Technical Report 1562
Volume 1
February 1993

System Investigation Into the Applicability of

LAMPS MK III Assets to Implement a High Data Rate Ship-to-Ship Communication System

James P. Rahilly

Technical Report 1562
Volume 1
February 1993

System Investigation Into the Applicability of

LAMPS MK III Assets to Implement a High Data Rate Ship-to-Ship Communication System

James P. Rahilly

NAVAL COMMAND, CONTROL AND
OCEAN SURVEILLANCE CENTER
RDT&E DIVISION
San Diego, California 92152-5000

J. D. FONTANA, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

The Naval Command, Control and Ocean Surveillance Center, RDT&E Division, Code 824 has prepared this report. James P. Rahilly is directing this effort as the Principal Investigator under a 6.2 Communication Block funded Chief of Naval Research (CNR) task.

Released by
J. B. Rhode, Head
Electromagnetic Technology
and Systems Branch

Under authority of
R. J. Kochanski, Head
Communications Systems
Engineering and
Integration Division

CONTENTS

FIGURES

EXECUTIVE SUMMARY

The Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division has over the previous year been exploring the technology and system approaches that could provide, on a minimum development cost basis, a High Data Rate (HDR) communication link connectivity between surface ship elements of a U.S. Navy battle force. HDR is defined as being data rates equal or greater than the Bell T1 rate of 1.54 Mbps.

Because of the extremely high development cost and likelihood of shipboard cosite electromagnetic interference (EMI) compatibility problems, the creation of a brand new superhigh frequency (SHF) communication system was felt to be the least viable way of achieving this HDR capability on U.S. Navy combatant ships. After exploring a number of alternative approaches that would directly use or augment existing shipboard electronic systems there appeared to be virtually no viable candidates. However, a system was discovered that did offer HDR communication potential, and it is called the Light Airborne Multipurpose System (LAMPS) MK III. The investigation of LAMPS MK III was directed at revealing how its design features could be used to achieve a line-of-sight (LOS) shipboard HDR communication system. A ground rule was that any changes to LAMPS MK III would not cause any change in its capability to perform its operational helicopter mission of antisubmarine warfare (ASW) and antiship surveillance and targeting (ASST) data collection and HDR data transmission to its mother ship.

This report prepared at the unclassified level does not discuss the LAMPS MK III data rates and specific operating frequencies. The analysis of the HDR communication system performance for the ship-to-ship LOS ranges using LAMPS MK III is not affected by these restrictions since this analysis is based on other factors such as antenna gain, the output power of new solid state (SS) power amplifiers (PA), the use of the internationally accepted mobile SHF operating frequency band (4.4 to 5.0 GHz), and technical information on the LAMPS MK III that is available in unclassified references. Solid state PA information was for example based on recent advances in the field of solid state SHF radio frequency (RF) power amplifiers that offer highly reliable, power efficient, and low cost application of this technology in the use of 40-watt power amplifier devices in the above frequency band.

In this report, data transmitted from the ARQ-44 Radio Terminal Set (RTS), i.e., the helicopter assets, will be referred to as the wideband data (WB). The data transmitted from the surface ship are referred to as narrowband data (NB). These distinctions are necessary to avoid confusion when discussing various aspects of a new proposed concept. Basically this new concept proposes the installation of the LAMPS MK III helicopter RTS assets (ARQ-44) into a LAMPS MK III surface ship and integration with its onboard RTS SRQ-4. We discuss the various implementation approaches that can be developed using this concept and the issues that develop when integrating these two different RTSs.

This report describes the significant new full duplex NB or WB capability that might be achieved using this new concept. For example, a NB mode of operation appears to offer a capability for ship-to-ship networking with up to 16 ships using omnidirectional antennas and operating at about 1[illegible]-kbps data rate. Also of interest is the link analysis results obtained for a number of system configurations showing ship-to-ship WB communication data rates of about 5 Mbps can be achieved without multi-path interference out to a LOS limit of 20 nmi at an extremely low-bit error rate. As an example, one of these configurations uses a special HDR transmit communication package that is built around the ARQ-44 RTS assets that would otherwise be located below deck. A 6-dB omni antenna is directly coupled to the RTS package to avoid RF line losses. In this concept, the shipboard SRQ-4 is completely separate from the WB communication package since it is mounted as high as possible on the ship. The interface with the below deck equipment will be either at intermediate frequency (IF) or at baseband. Coaxial cable would be used to connect the package to below deck thus avoiding long lengths of lossy waveguide. The advantage of this approach stems not only from a reduction in RF line losses but also because of its compactness. As an illustration, this communication package might be used for HDR transmission at the 5-Mbps rate from non-LAMPS MK III ships, such as aircraft carriers, or shore locations to conventional LAMPS MK III ships.

Volume II will be published shortly and report on the impact that LAMPS MK III system test measurements, made by NESEA, has had on the design of the HDR LAMPS MK III communication system. Preliminary findings from these data indicate that in many ways certain issues in the operational and test system designs have become easier than the theoretical assessment.

Volume III is planned for later in FY 93 and will provide detail design information on the temporary changes that will be made in LAMPS MK III to conduct ship-to-ship HDR testing. In addition, the results of a study of methods to ensure the lowest probability of intercept (LPI) of a shipboard HDR transmitter will be presented.

1.0 INTRODUCTION

The financial support for this technical investigation has been provided under the NCCOSC RDT&E Division's 6.2 Communication Block Funding Program. The technical approach that evolved is directed at the application of the current Navy LAMPS III assets to satisfy the 6.2 program SHF HDR ship-to-ship communication objectives. This use of LAMPS III is considered to be the most viable and cost effective way the Navy can provide its combatant ships with a HDR ship-to-ship communications. This new capability is to be in the SHF band. HDR is defined as the Bell T1 rate of 1.544 Mbps or higher. This report shows that the application of LAMPS III to this requirement permits ship-to-ship data communication using rates in excess of three times the T1 rate at 20-nmi range separation. Figure 1.1 provides a photograph of the uninstalled LAMPS III shipboard system (SRQ-4). Figure 1.2 shows the LAMPS III SH60R helicopter after it's takeoff from a LAMPS III equipped FF 8 (Fast Frigate Class). The ASW and ASST data that the LAMPS helicopter collects while on station are transmitted at HDR back to, in this case, an FFG. The Navy has in excess of 57 major combatant ships at sea with the LAMPS III. The LAMPS antenna installation locations on a DD 963 are shown in figure 1.3. Figure 1.4 shows a list of these ships that includes CG, DD 963, DDG 51, and FFG ship classes. Counting planned installations, shore and ship total will be about 117. The discussions will be kept at the unclassified level and a companion supplement (volume 2) at the classified level is for those who have need for detailed sensitive information on LAMPS III operational communication system parameters and related technical concepts.

2.0 DISCUSSION

In the early phases of the investigation, technical issues were examined and conclusions reached that led to the belief that LAMPS III was the optimum way to achieve a HDR ship-to-ship communication capability. For example, the scope of the investigation required the consideration of the entire SHF band. However, as a result of a review of the allowable electromagnetic frequency regions in the SHF band, where mobile LOS ship-to-ship communications are permitted by international agreement, we found that only the spectral region from 4.4 to 5.0 GHz was allocated for this purpose. Therefore, for the same reasons, this also is the specific operating frequency band used by LAMPS III, to perform its communication linking between the LAMPS III ship and LAMPS III helicopter.

Another technical issue relates to the assessment of the electromagnetic compatibility of any newly created communication system in the existing LAMPS shipboard transmitter and receiver operating environment. For example, any newly created system that is to operate in the same 4.4- to 5.0-GHz frequency band as the LAMPS III system must not interfere with the high priority communication linkage between the ship and the SH-60B helicopter. A ship-to-ship SHF HDR communication system that is currently under development is finding this issue to be a major consideration. The approach taken in this new ship-to-ship HDR communication concept is to not create a

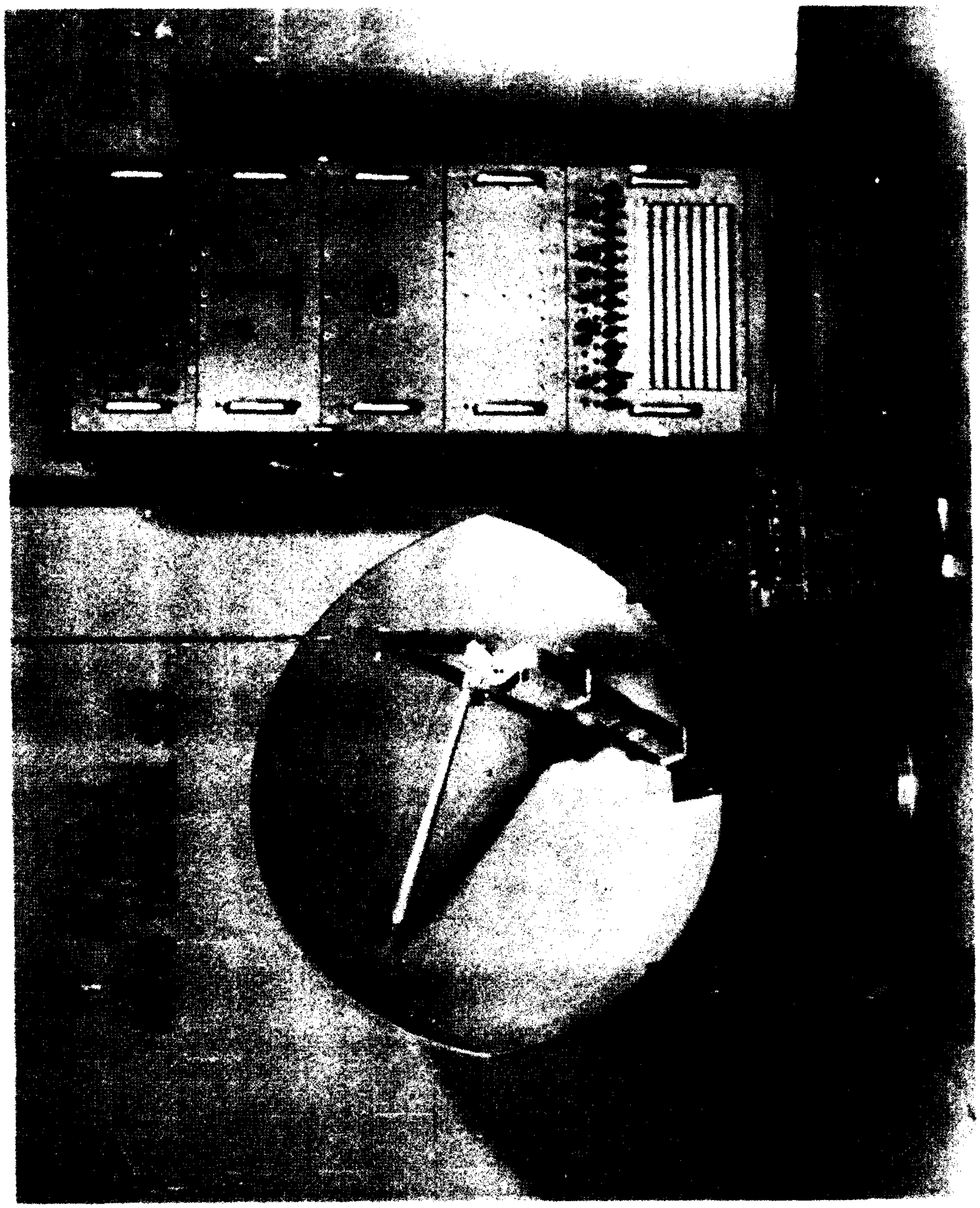


Figure 1.1. AN/SRQ-4 radio terminal set.

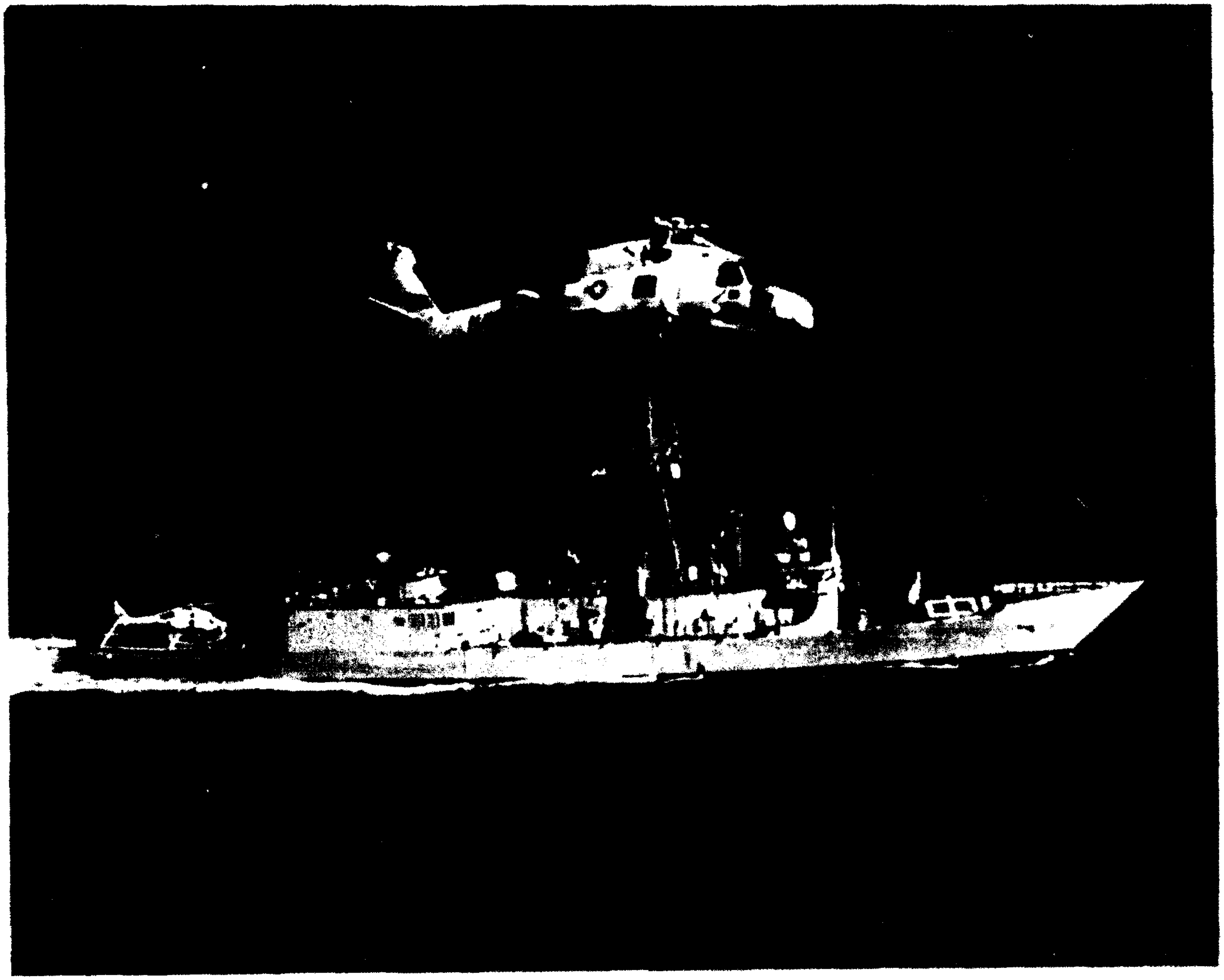


Figure 1.2. LAMPS III SH60R helicopter after takeoff from a LAMP III equipped FF8.

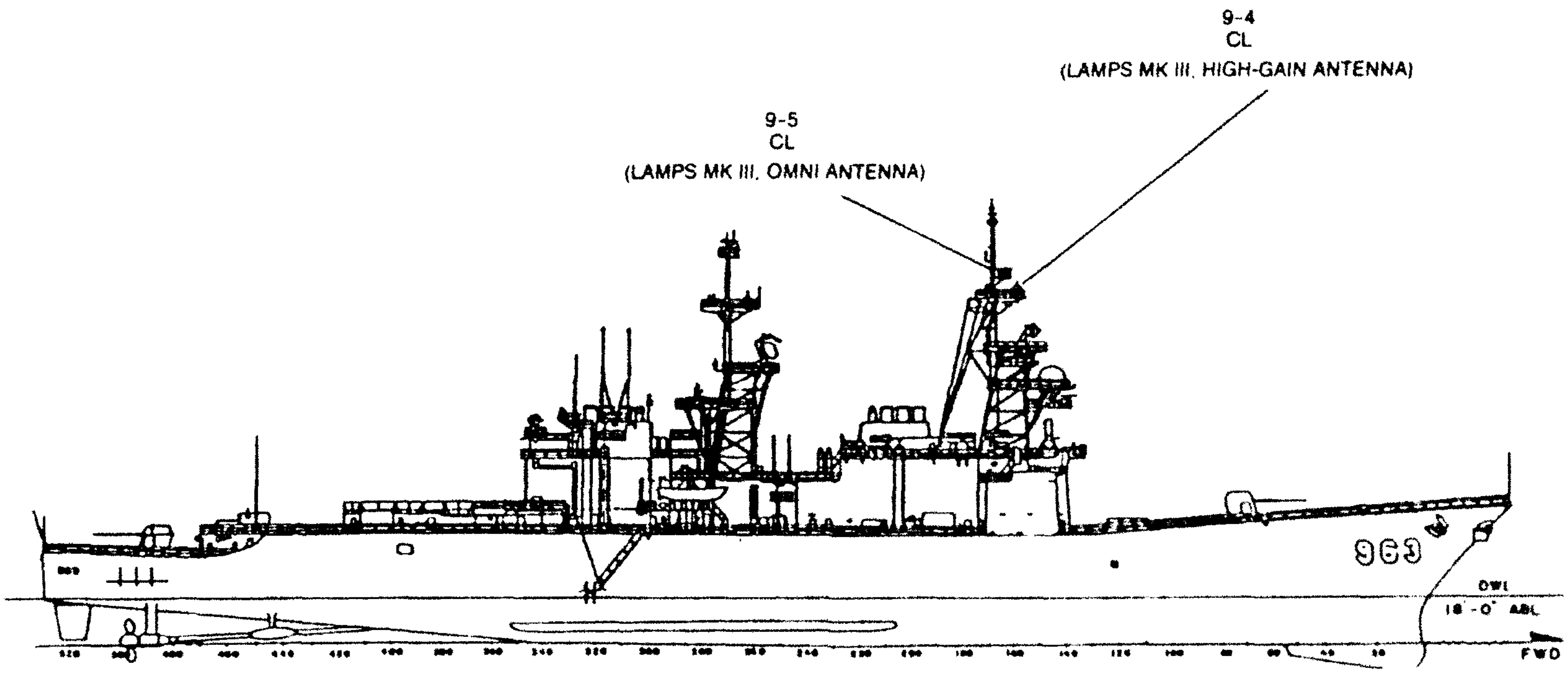


Figure 1.3. DD963 Starboard profile.

QTY	HULL NO.	NAME	CLASS	HOMEPORT
1	CG-49	VINCENNES	CG-47	SAN DIEGO
1	CG-50	VALLEY FORGE	CG-47	SAN DEIGO
1	CG-51	THOMAS S. GATES	CG-47	NORFOLK
1	CG-52	BUNKER HILL	CG-47	YOKOSUKA
1	CG-53	MOBILE BAY	CG-47	MAYPORT
1	CG-54	ANTIETAM	CG-47	LONG BEACH
1	CG-55	LEYTE GULF	CG-47	MAYPORT
1	CG-58	PHILLIPPINE SEA	CG-47	MAYPORT
1	CG-59	PRINCETON	CG-47	LONG BEACH
1	CG-60	NORMANDY	CG-47	NEW YORK
1	CG-61	MONTEREY	CG-47	MAYPORT
1	CG-62	CHANCELLORSVILLE	CG-47	SAN DIEGO
1	CG-64	GETTYSBURG	CG-47	MAYPORT
1	CG-65	CHOSIN	CG-47	PEARL HARBOR
1	DD-963	SPRUANCE	DD-963	MAYPORT
1	DD-964	PAUL F. FOSTER	DD-963	LONG BEACH
1	DD-965	KINKAID	DD-963	SAN DIEGO
1	DD-966	HEWITT	DD-963	YOKOSUKA
1	DD-967	ELLIOT	DD-963	SAN DIEGO
1	DD-968	ARTHUR W. RADFORD	DD-963	NORFOLK
1	DD-971	DAVID R. RAY	DD-963	LONG BEACH
1	DD-974	COMTE DE GRASSE	DD-963	NORFOLK
1	DD-980	MOOSBRUGGER	DD-963	CHARLESTON
1	DD-981	JOHN HANCOCK	DD-963	MAYPORT
1	DD-001	FIFE	DD-963	YOKOSUKA
1	DD-992	FLETCHER	DD-963	PEARL HARBOR
1	FFG-8	MCINERNEY	FFG-7	MAYPORT
1	FFG-12	GEORGE PHILIP	FFG-7	LONG BEACH
1	FFG-28	BOONE	FFG-7	MAYPORT
1	FFG-29	STEPHEN W. GROVES	FFG-7	MAYPORT
1	FFG-33	JARRETT	FFG-7	LONG BEACH
1	FFG-36	UNDERWOOD	FFG-7	MAYPORT
1	FFG-38	CURTS	FFG-7	YOKOSUKA
1	FFG-40	HALYBURTON	FFG-7	CHARLESTON
1	FFG-41	MCCLUSKY	FFG-7	YOKOSUKA
1	FFG-42	KLAKRING	FFG-7	CHARLESTON
1	FFG-43	THACH	FFG-7	YOKOSUKA
1	FFG-45	DE WERT	FFG-7	CHARLESTON
1	FFG-46	RENTZ	FFG-7	SAN DIEGO
1	FFG-47	NICHOLAS	FFG-7	CHARLESTON
1	FFG-48	VANDEGRIFT	FFG-7	LONG BEACH
1	FFG-50	TAYLOR	FFG-7	CHARLESTON
1	FFG-51	GARY	FFG-7	LONG BEACH
1	FFG-52	CARR	FFG-7	CHARLESTON
1	FFG-53	HAWES	FFG-7	CHARLESTON
1	FFG-55	ELROD	FFG-7	CHARLESTON
1	FFG-56	SIMPSON	FFG-7	NEWPORT
1	FFG-57	REUBEN JAMES	FFG-7	PEARL HARBOR
1	FFG-58	SAMUEL B. ROBERTS	FFG-7	NEW PORT
1	FFG-59	KAUFFMAN	FFG-7	NEW PORT
1	FFG-60	RODNEY M. DAVIS	FFG-7	YOKOSUKA
1	FFG-61	INGRAHAM	FFG-7	LONG BEACH
1	CG-48	YORKTOWN	CG-47	NORFOLK
1	DDG-51	ARLEIGH BURKE	DDG-51	NORFOLK
1	FFG-32	JOHN L. HALL	FFG-7	MAYPORT
1	FFG-39	DOYLE	FFG-7	MAYPORT
1	FFG-49	ROBERT G. BRADLEY	FFG-7	CHARLESTON

Figure 1.4. The 57 ships with AN/SRQ-4 installed.

new system that might interfere with LAMPS but rather to use the LAMPS system itself to provide the ship-to-ship communications, when it is not performing its operational role with the LAMPS helicopter.

Other advantages in using the existing LAMPS system to achieve a ship-to-ship HDR capability includes the fact that the LAMPS high-gain antenna system, figure 1.1, is at a maximum height above the ship's deck. Real estate is very scarce at these heights and obtaining a location for a new high-gain antenna system at this height would be very difficult to do. The greater antenna height results in a greater LOS distance between ships.

Also, by using the LAMPS' antenna system there are no major developmental, procurement, or installation costs to obtain a new high-gain, stabilized antenna that provides monopulse azimuth tracking, that has passed mil-spec shock and vibration testing. The LAMPS III high-gain antenna has demonstrated highly successful operational reliability while providing mission support in conjunction with the LAMPS helicopter system.

The system's goal, in the proposed use of the LAMPS shipboard assets is to not only use the above deck assets but also to use, to a maximum degree, all the below deck subsystems. These subsystems include the frequency synthesizers, modulation, demodulation capabilities, transmit and receive subsystems, mux and demultiplex subsystems, and KG-45 cryptosystems. Data system interface issues are recognized and may ultimately cause a need for system flexibility and deviation from a complete adherence to present data framing, protocols, and timing methods. However, variations from the present LAMPS III design and/or implementation must carefully consider the requirement to be able to rapidly reconfigure the system from a posture that supports ship-to-ship HDR communication to one that can immediately support the LAMPS III mission. The LAMPS III mission must always be the primary operational mode and any design changes must always be evaluated from this perspective.

3.0 DESCRIPTION OF LAMPS COMMUNICATION CONCEPTS

To effectively discuss the new HDR communications concepts, it is best to first examine how LAMPS communications presently operates. Figure 3.1 shows the basic facets of LAMPS ship-helicopter communications. The shipboard LAMPS transmit and receive equipments are below deck and connected to either the high-gain or omni antennas, that are mounted high up on the ship, by waveguide through the waveguide switch shown in figure 3.1. This figure shows the high-gain antenna having been selected. This antenna mode is used when the helicopter is greater than 2-nmi distance from the ship. The uplink requires less than 10 percent of the bandwidth required by the helicopter to ship downlink. Therefore, the terms wideband (WB) and narrowband (NB) have been used to distinguish these two links. The WB downlink includes the NB response data, since it is multiplexed in with the WB downlink data stream. Thus a full duplex communication is achieved relative to the NB data communication. The WB link is simplex in nature, since there currently is no need for WB transmission from the LAMPS ship to the helicopter.

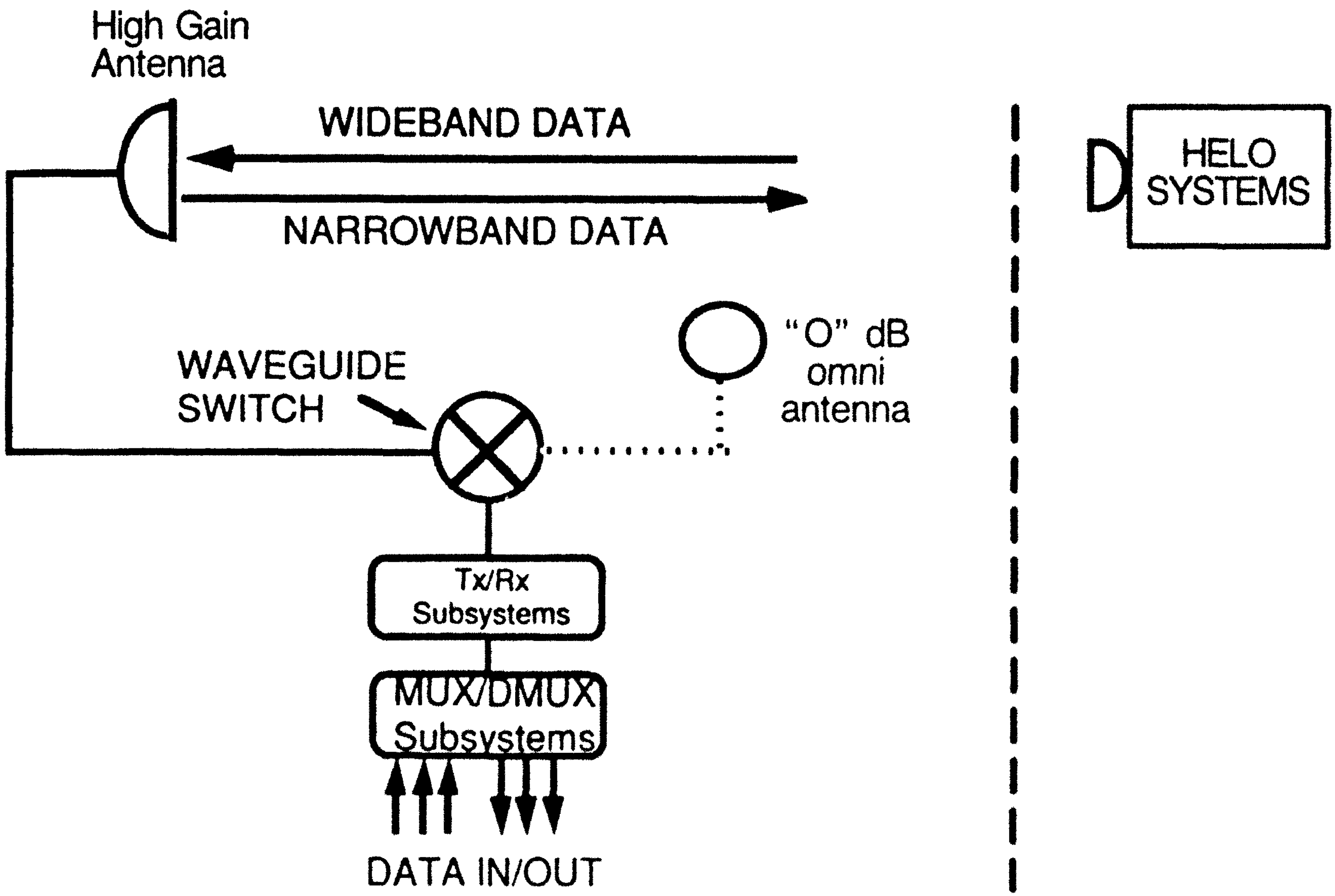


Figure 3.1. Present shipboard LAMPS III system (SRQ-4).

3.1 BASELINE LAMPS COMMUNICATION CONCEPT

The baseline LAMPS HDR communication concept is aimed at a maximum communication capability and is created on the ship by integrating the shipboard LAMPS system (SRQ-4) together with the LAMPS III WB transmit, NB receive, and mux demux assets that are identical to that used by the SH-60B LAMPS III helicopter (ARQ-44). Figure 3.2 illustrates this concept. In this figure a new dual rotary waveguide switch is required to replace the present single-action switch. In the waveguide switch position shown, the SRQ-4 receive and transmit system is connected to the high-gain antenna, while the ARQ-44 is connected to the omni antenna. This is the ship A configuration. Ship B at the other end of the link has its configuration just reversed. Figure 3.2 shows that the high-gain antennas are transmitting the NB data links and the zero dB-gain omni antennas are transmitting on the WB data links. Therefore, the high-gain antenna's monopulse angle tracking system will use the WB signal from the omni antenna for antenna steering commands. It should also be noted that NB operation is conducted in a lower band (LB) and upper band (UB). WB operation can be performed in the band not used for NB. The resulting frequency separation between NB and WB is required to achieve the needed isolation between the transmitted energy and the low level signals that are being simultaneously received. This signal isolation is presently obtained using a diplexer consisting of two broadband RF bandpass filters; one designed for the LB and one for UB operating frequency bands.

The filter bands for ship A (i.e., NB UB Tx and WB LB Rx) are presently provided by the SRQ-4 diplexer filters. However, ship B would require new diplexing filters to satisfy the new NB LB Tx and the WB UB Rx requirements. To allow flexible operational configurations the diplexing filters would have to allow a remotely controlled switchable filter design. The filter arrangement presently provides a diplexer with as much as 90 dB of isolation between the receive and transmit signals. The simplest way to visualize the use of the UB and LB is as follows. Referring to figure 3.2, first examine the band use by the high-gain antenna on ship A and the omni antenna on ship B. In this situation, the high-gain antenna on ship A is transmitting in NB in the UB of the 4.4- to 5.0-GHz allocation, and the WB signal is being received in the LB (i.e., in a lower band in this allocation). This is exactly the same situation that exists when ship B is replaced by the LAMPS helicopter, since it operates in these bands. Therefore, examining the omni on ship B, we see that, like the helicopter, it is transmitting WB in the LB and receiving NB in the UB. Therefore, on each of the platforms, the separation between the diplexer bandpass filters, located in the UB and LB is the same and is sufficient that transmission and reception can occur simultaneously without causing corruption of the quality of the received data.

The links between the omni antenna on ship A and the high-gain antenna on ship B are reversed from what has just been observed for ship A. The reason for this can be explained. Consider first the omni on ship A. We note that it is radiating a WB signal in UB and receiving a NB signal in a LB. From the foregoing, the high-gain antenna on ship A was receiving WB in the LB. Therefore, for the collocated omni antenna WB emissions not to interfere with the high-gain antenna WB receptions on ship A, it is

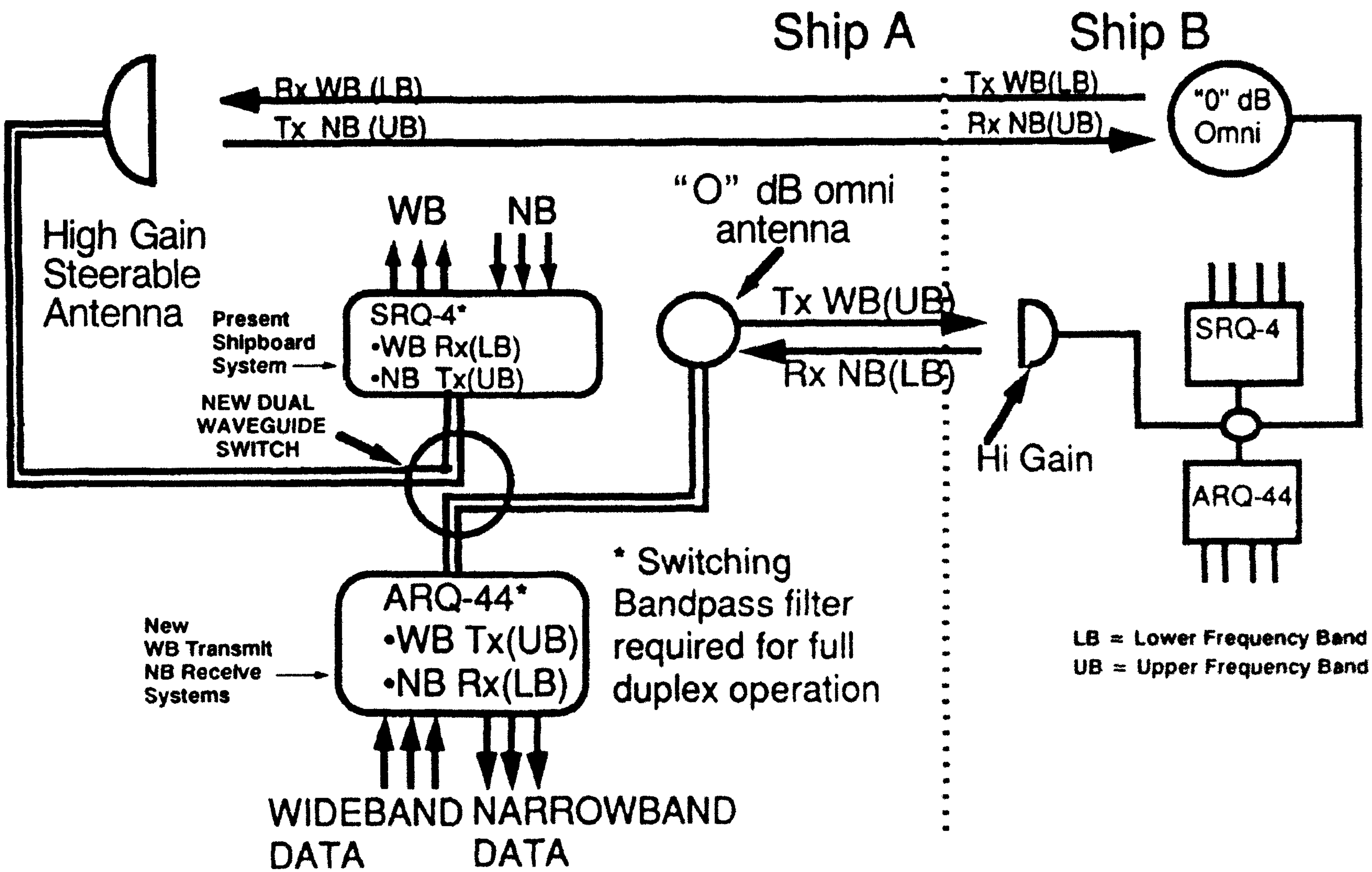


Figure 3.2. LAMPS III modification for full duplex wideband (WB) and narrowband (NB) data ship-to-ship communication.

necessary that isolation be achieved by having the WB receive and transmit bands as far apart as possible. This isolation is achieved by having the omni antenna WB transmit band in a UB since the WB received by the high-gain antenna is in a LB. The same logic applies to the NB reception in the LB by the omni antenna. Likewise, the LB NB signals transmitted by the high-gain antenna on ship B requires that ship B WB reception occur in the UB. The UB bandpass RF filter for WB transmit and receive functions and LB RF filter for NB transmit and receive functions do not now exist in the present LAMPS system and would have to be fabricated and sized for installation in the LAMPS R/T drawer in the shipboard system and R/T module in the helicopter configuration. Furthermore, these new bands would have to occupy the available spectrum after the WB LB and NB UB used by LAMPS III, has been allowed for. Figure 3.3 shows in generalized terms what this frequency band allocation would look like. The detailed numerical assignment for the frequencies are not shown and may be found in volume 2.

Because the new WB UB and NB LB diplexing bandpass filters use the available spectrum between the existing filters (see Figure 3.3), there is a significant reduction in the separation between the filters. Whether the present 90-dB isolation can be achieved or not remains to be determined. If the isolation level is unsatisfactory for simultaneous full duplex WB and NB operation, then nonsimultaneous WB or NB full duplex communication mode could be used quite satisfactorily. Flexibility in the selection of a filter configuration on a particular ship will require the ability to remotely switch the filters to the desired compatible WB/NB characteristics. However, one must bear in mind that in the foregoing example we have, using the present LAMPS communication architecture, attempted to create two simultaneous full duplex links; one for NB and the other for WB communication. From a practical standpoint there may be merit in operating ship-to-ship in either a NB or WB mode. These concepts will be more fully developed later. To achieve the WB/NB capability shown in figure 3.2, the following would be added to the basic capability offered by the LAMPS assets to equip two test ships:

1. Two dual waveguide switches
2. Two WB UB RF bandpass filters; see figure 3.3
3. Two NB LB RF bandpass filters; see figure 3.3
4. Two SMA type switches at input to the R/T subsystems.
5. Two modifications to frequency synthesizers to permit shifting references in accordance with the new WB UB and NB LB while still being capable of meeting LAMPS transmit and receive bands and channelization in receive and transmit operation.

Volume 2 provides a simplified approach to a demonstration system that is different from this baseline. This approach was possible because of the advantages offered by LAMPS fabrication characteristics that were discovered as a result of laboratory testing.

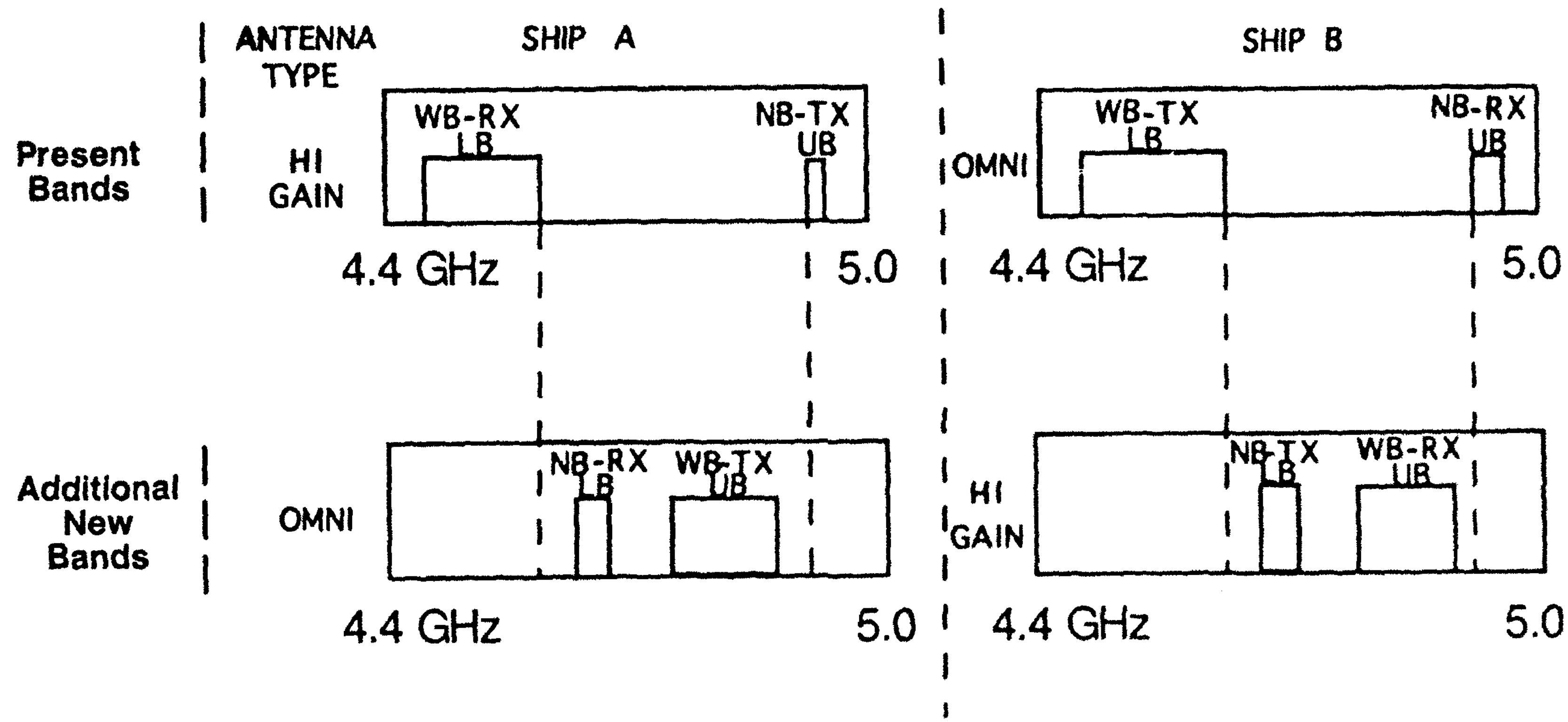


Figure 3.3. Idealized diplexer bandpass filters for full duplex WB together with NB ship-to-ship data communications using LAMPS III.

3.2 LAMPS SPECIAL COMMUNICATION PACKAGE

For this different LAMPS communication system configuration an examination has been made of the value that might be derived in the WB transmit/NB receive modes if the constraint of using only the LAMPS antennas and waveguide was removed on the ARQ-44 side. In the configuration shown in figure 3.4 a new shipboard communication package is depicted. The concept creates a separate NB receive/WB transmit package that can, by being separate from the SRQ-4, be mounted high up on the ship mast (80 to 100 feet) and use the R/T modules that come from the LAMPS helicopter (ARQ-44) assets. This package also contains the needed diplexer filters directly connected to an omni antenna with a 6-dB gain near the horizon. The interface between the new communication package and the equipment below deck is at IF or baseband. Therefore, long lengths of waveguide, joints, and couplings with attendant loses are eliminated. The antenna to R/T subsystems losses, because of the short run will be very low. Therefore, the transmitted RF WB radiated power will be about 11 to 14 dB higher than the foregoing baseline design when the LAMPS omni antenna is used for WB transmission. Therefore, some new capabilities are now possible. Figure 3.4 shows how a networking NB mode can be achieved between various ships using the LAMPS multichannel design without having to steer a directional antenna. In figure 3.4, NB full duplex communications can be achieved using the LAMPS omni antennas and the 6-dB antenna in the new communication package. From this figure we see that ship A is transmitting NB in the LB while reception occurs with the 6-dB antenna on ship B. The other half of the duplex operation is created by transmitting NB in the UB from ship B using the LAMPS omni. This signal is received by the 6-dB omni on ship A. Since the LAMPS system is channelized in both the NB and WB modes, each of the users can have any one of a number of RF channels as his own call sign. Any other ship within LOS of the antenna system can listen to him transmitting on his channel and determine whether he wants to receive the traffic. In the NB mode, it will be possible to send and receive high quality encrypted voice with the existing ship's LAMPS encrypted voice capability. If the interaction between the various ships is heavy relative to data exchanges, a time division multiplexing technique might be developed to efficiently exchange data between all users. In this arrangement, each user would have a specific time slot for his transmission on his specific channel.

Figure 3.5 shows how two ships in the NB net having decided over the NB net that they want to go into the WB full duplex mode can do so without disrupting their NB net connectivity. From figure 3.5 we can see that high-gain directive antenna has now replaced the "0" dB omni on both ships and is now working in conjunction with the 6-dB omni antennas. Examining figure 3.5, one can see, relative to figure 3.2, that except for 6 dB more gain and reduced line losses, that the links are the same. In LAMPS, the number of channels in the WB mode is the same as in the NB mode. With the new communication package the high-gain antenna will Tx/Rx with a 6-dB omni antenna with up to 8 dB less line loss. Therefore, improved receive signal strength will permit WB data communication at even lower bit-error rates. Similarly, the NB links are more robust and error free than would occur if only the LAMPS "0" dB omni antenna was used.

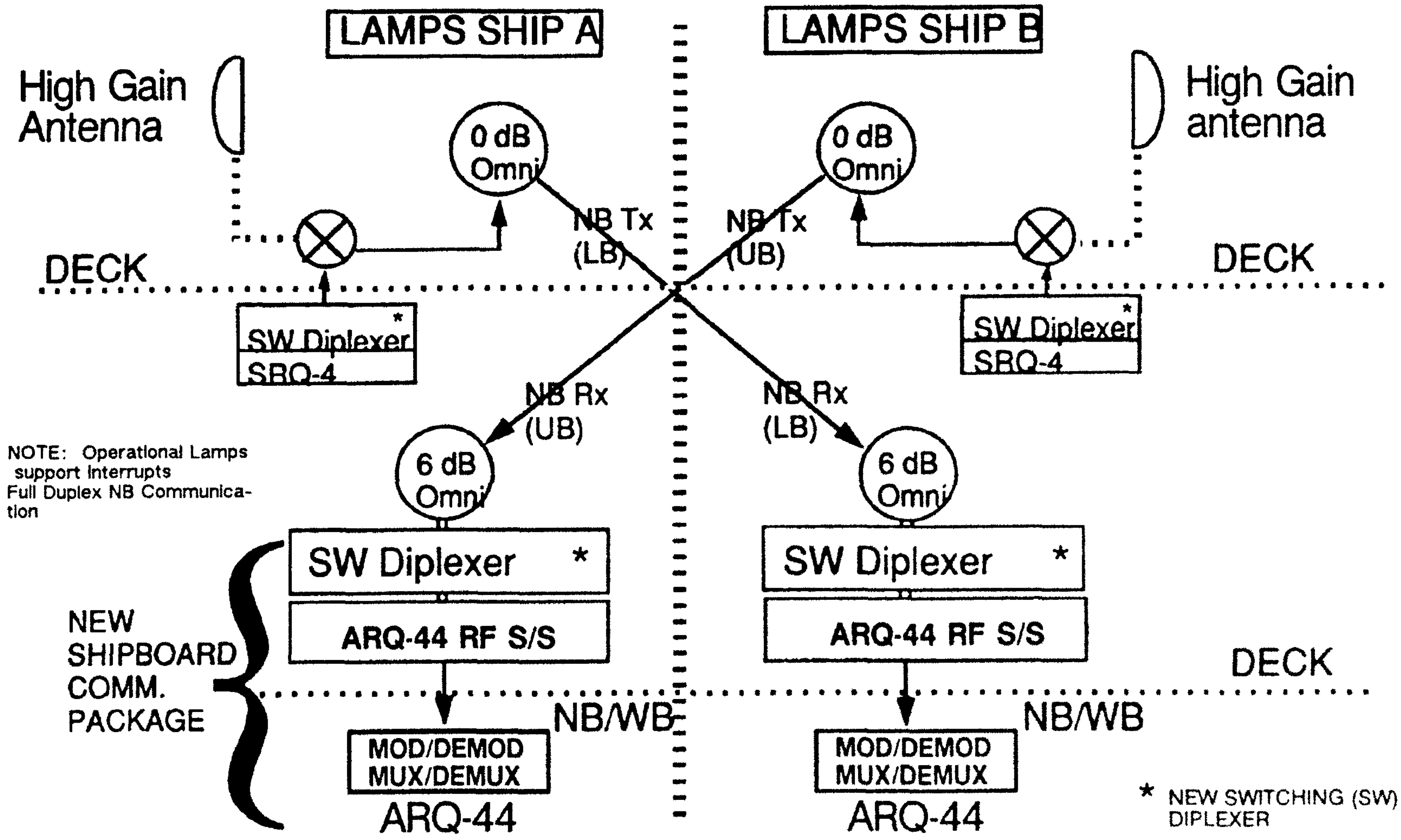


Figure 3.4. Full duplex narrowband (NB) ship-to-ship communication using a modified SRQ-4 with a separate new ARQ-44-based communication package on each ship.

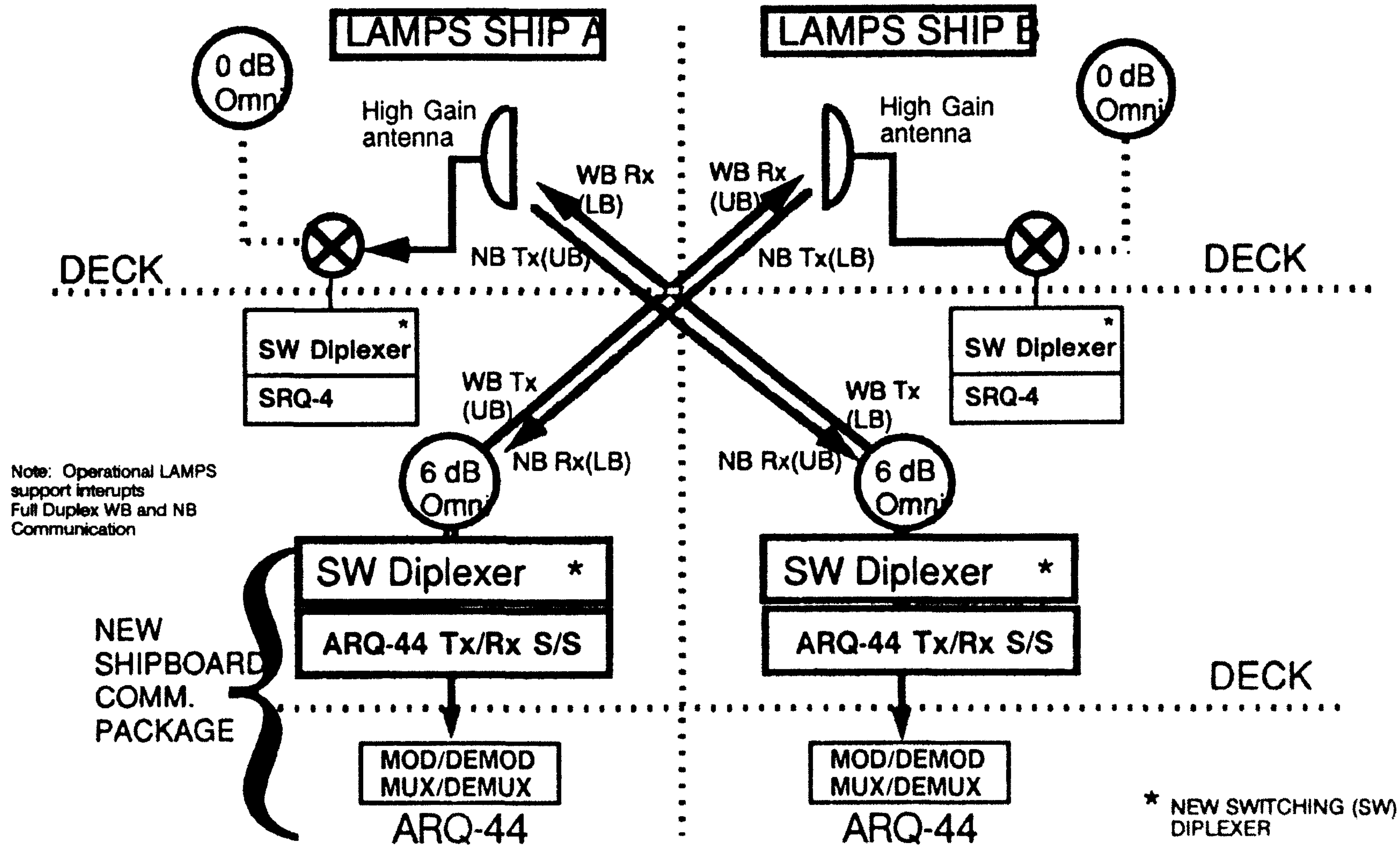


Figure 3.5. Full duplex wideband (WB) and narrowband (NB) ship-to-ship communication using the new communication package that provided a full duplex NB capability.

Figure 3.6 shows how the communication package just described could be used to provide a HDR link from a non-LAMPS ship (e.g., an aircraft carrier) or a land site. This capability would also allow full duplex NB data operation between the two ships or a land site and the LAMPS ship. This capability could have been particularly useful during the Persian Gulf War.

Figure 3.7 shows more detail relative to how the new WB-UB and NB-LB diplexer filtering could be done in the operational shipboard ARQ-44 communication package. The shaded area contains the currently used WB-LB and NB-UB bandpass diplexer filters as they are in the ARQ-44 system. The switches shown connecting the filters to the ARQ-44 transmit and receive chains are new. Examining this figure we note that when the switches allow connectivity to the filters on the left side, we have the present configuration. When the switches are set to connect to the nonshaded filters on the right, we then have the new transmit WB-UB and receive NB-LB bandpass filter configuration. Thus for the communication package to operate on ship B, in figure 3.5, the two RF switches would be set to operate with the filters in the shaded area. Flipping the switches in the special communication package to the other position is required for ship A and would allow connectivity to the bandpass filters in the unshaded area. This would give the WB-UB needed for ship A WB transmit and the NB-LB filter needed for reception on ship A. The characteristics of these switchable filters might theoretically be the same as described in figure 3.3. We noted that concurrent with the switching of these filters there is also a need to switch the transmit and receive downconverter and modulator synthesizer frequency references, so that receive and transmitter frequency and channel alignment is always maintained. The ARQ-44 LAMPS helicopter electronic equipment comes in two modules, referred to as UNITS 1 AND 2. Figure 3.7 assumes that a baseband interface can be created to eliminate the need for a waveguide connection to the rest of the equipment located below deck. An IF interface would also be acceptable. A similar discussion would apply to the SRQ-4 shipboard diplexer switching shown in figure 3.8, as for the ARQ-44 system. However, one difference is that, in figure 3.8, the transmit and receive subsystems are installed in one drawer mounted in a large rack and the digital multiplex and demultiplex equipment is in another drawer. There fortunately is a reasonable amount of space in the receive/transmit drawer to install the new RF diplexer filters shown unshaded along with the new SMA style switches and RF conductors. The available space in the ARQ-44 Unit #2 (R/T subsystem) is much more limited and therefore poses much more of an engineering challenge. As in the ARQ-44 system, there is also a need in the SRQ-4 to modify the transmit and receive and channelization frequency reference systems so that the RF frequency swings dictated by the operating regions of the new diplexer filters can also be accommodated. As stated earlier, the supplement volume will discuss another version of the foregoing that is possible because of the actual measured LAMPS III characteristics.

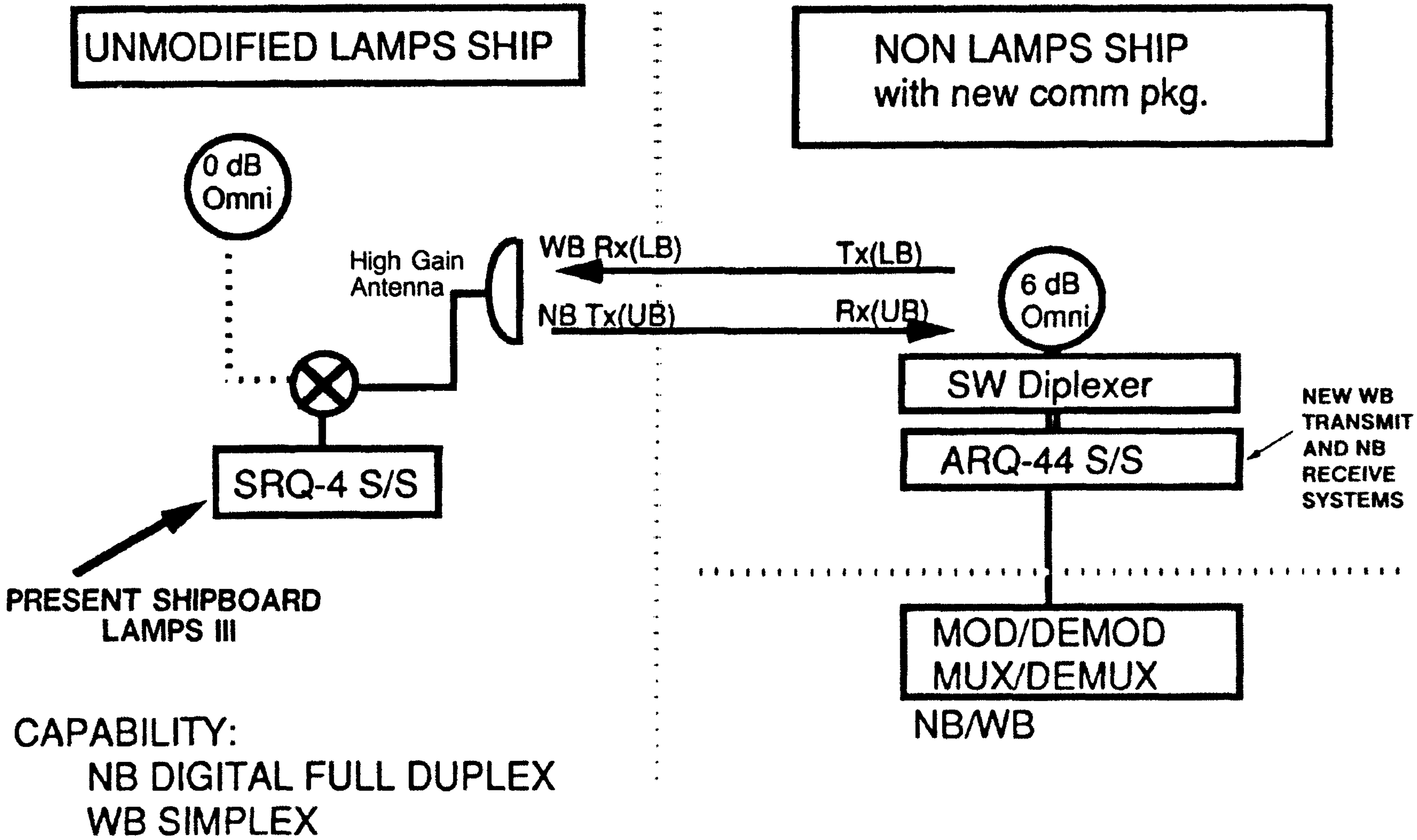


Figure 3.6. Special LAMPS III link using the new ARQ-44-based communication package.

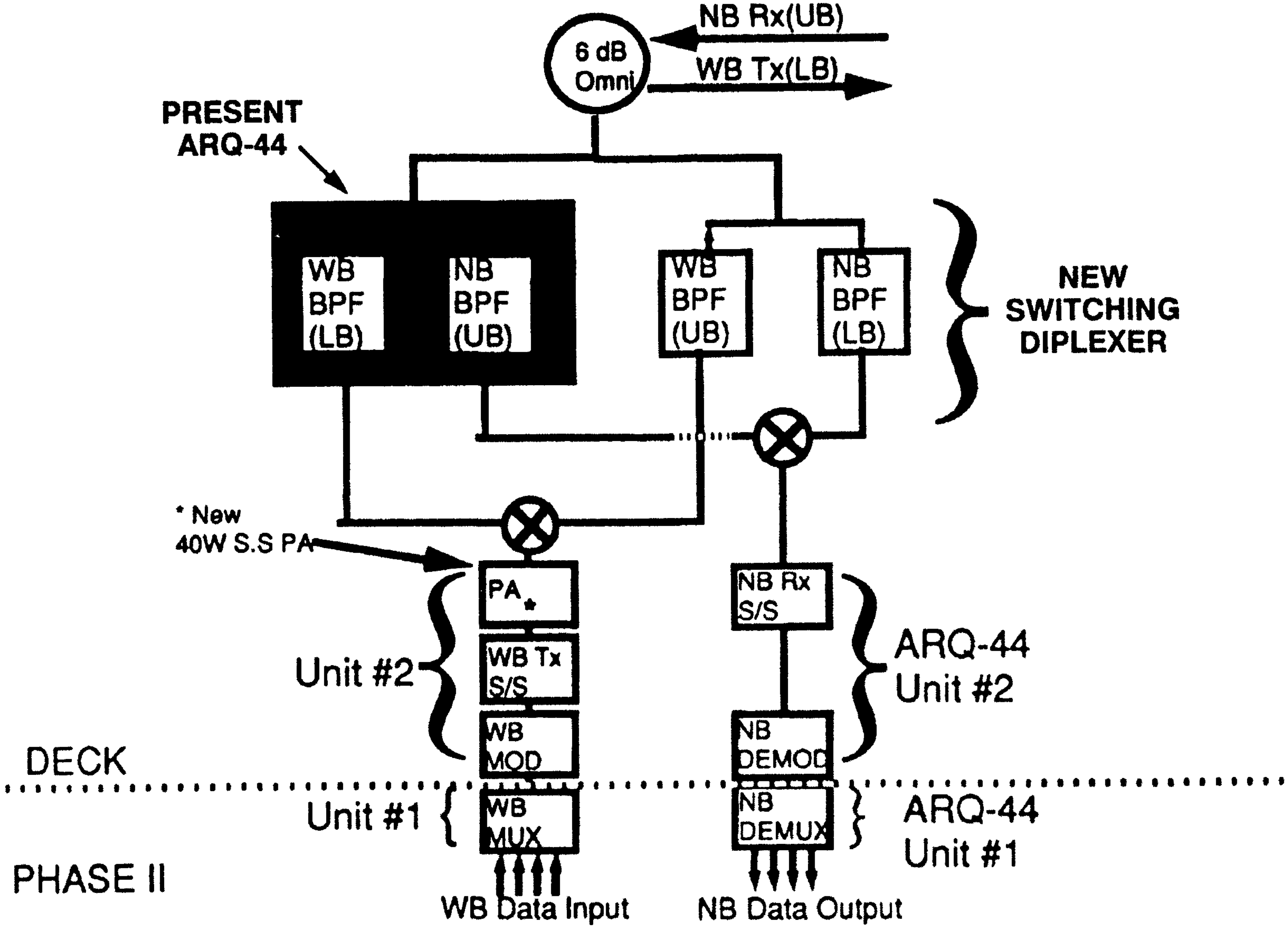


Figure 3.7. New shipboard communication package using ARQ-44 S/S assets.

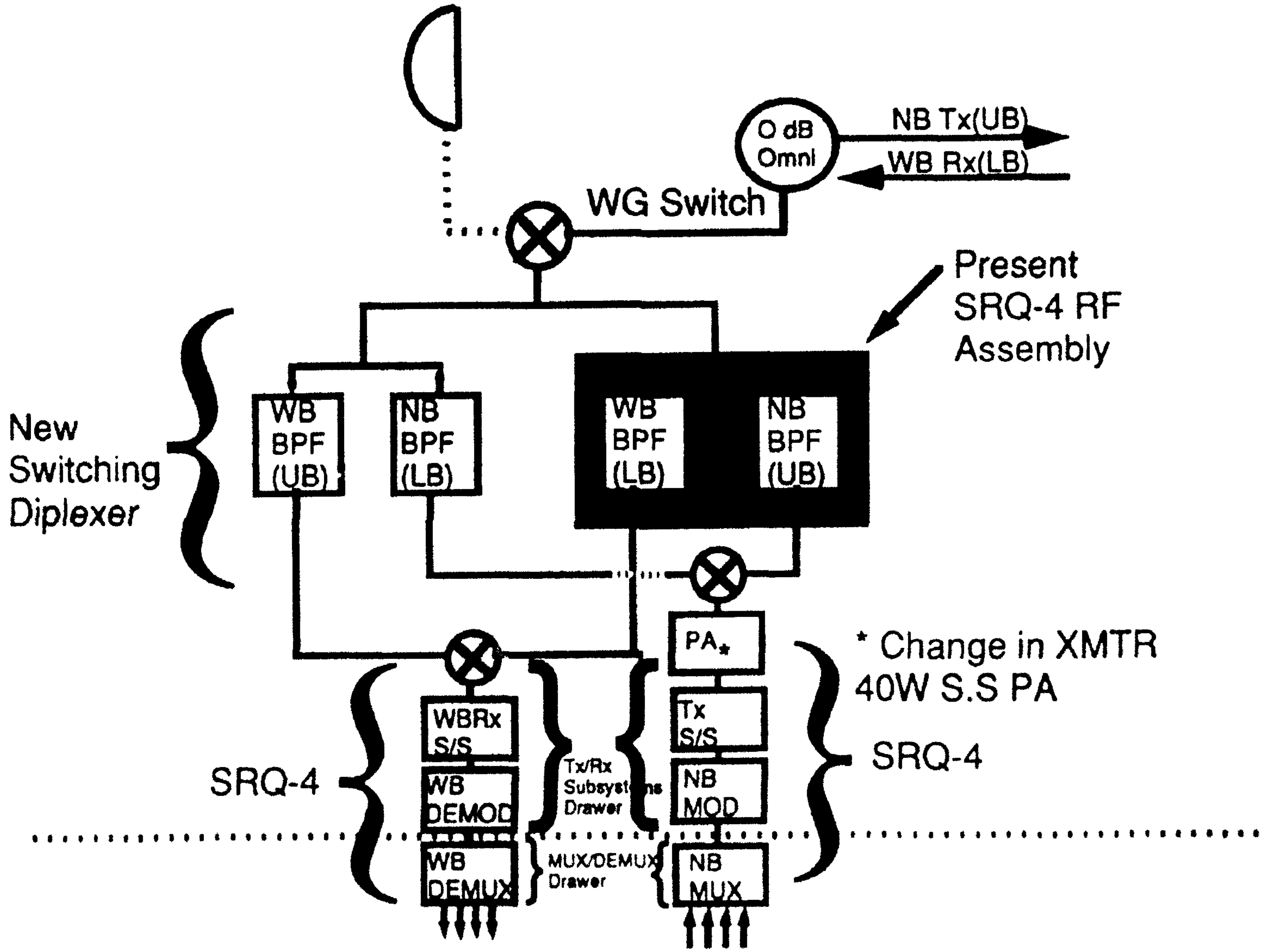


Figure 3.8. SRQ-4 shipboard system modified with a switching diplexer.

3.3 FULLY INDEPENDENT WB AND NB SHIP-TO-SHIP DATA LINKS

In the earlier systems discussed, all cases had the WB and NB communication links both operating simultaneously through either the high-gain or the omni antenna. Since operationally this could limit the full use of the capability associated with the LAMPS III subsystems, the configuration shown in figure 3.9 was examined. Independent connectivity can be seen by noting the fact that the high-gain antenna is for both WB transmit and WB receive, and the "0" dB omni antenna is both NB transmit and NB receive, for the waveguide switch position shown. If this switch is rotated to the other position the connectivity would still be independent but reversed i.e., only WB would be connected to the "0" dB omni and only NB would be connected with the high-gain antenna. This independence allows full duplex operation for WB or NB through a single antenna. The antennas on ship B can be configured for high gain to high gain, high gain to omni, or omni to omni. The high gain to high gain WB could be used to achieve maximum directivity and minimum RF transmitter power so that a Low Probability of Intercept (LPI) would occur while transmitting large databases in the WB data mode. The omni to omni case could be used for a NB networking operation independent of the WB operation being conducted between the two high gain antennas.

The foregoing functional capability can be accomplished by a revision of the present RF diplexer system. If one examines, for example, the section of figure 3.9 that addresses the modified ARQ-44, we can see that, there is a WB Tx output in the LB. However, a WB output is also shown as possible in the UB. Thus the ARQ-44 system has been now modified to have a band-pass filter for both the upper and lower WB transmit bands. Similarly, the ARQ-44 NB receive is, as normal, receiving in the upper band. However, it also is able to receive in the lower band. To do this, the original WB-LB Tx and NB-UB Rx diplexer has been functionally split apart so that the new WB LB/UB and NB LB/UB bandpass filtering can be created. The discussion regarding the modified SRQ-4 follows along the same lines as the ARQ-44 viz. WB Rx in the LB is normal and WB Rx filter in the UB is now required; similarly, with the NB portion of the modified SRQ-4 system.

With this new independent system, the Rx/Tx diplexing is performed external to the ARQ-44 and SRQ-4 as in figure 3.9. The WB Tx and Rx meet at a common junction that has connectivity to waveguide switch A via switch B. A requirement exists for control between the ARQ-44 and SRQ-4 such that only WB-UB Tx can occur when WB-LB Rx is selected. When WB-LB Tx is selected then only WB-UB Rx can be allowed. This assures that the needed transmitter to receive isolation will be in place to protect the RF preamplifier and to minimize interfering transmitter noise level in the receive system.

Finally we note that the independent configuration is sufficiently different from the original LAMPS design so that it cannot be easily reconfigured to go back to its original LAMPS architecture. Nevertheless, this can be solved by connecting a SRQ-4 in through waveguide switch B in figure 3.9. When operational requirements dictate LAMPS operational support, this waveguide switch is thrown disconnecting the modified independent system. The high-gain antenna now is performing in its normal

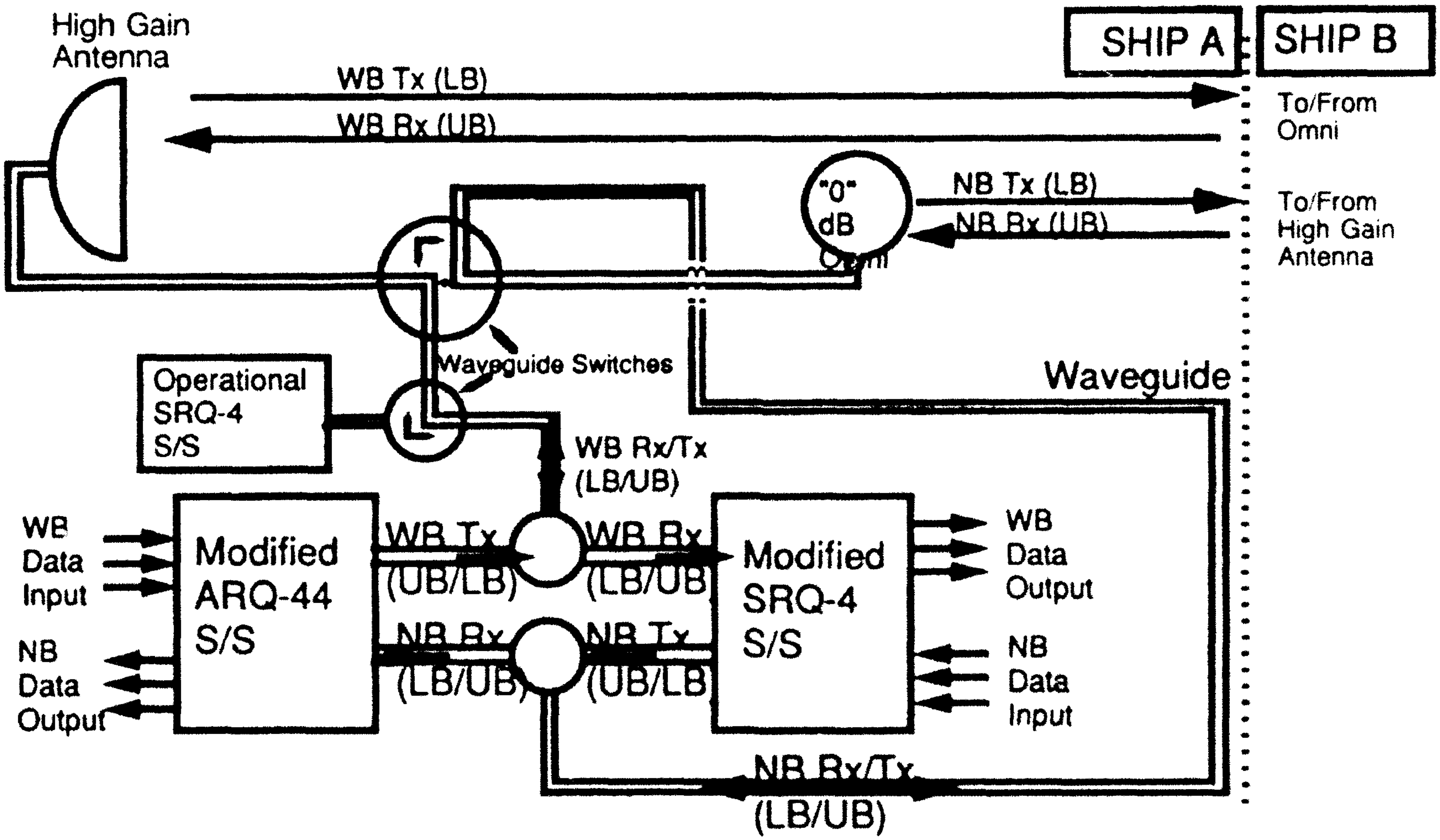


Figure 3.9. Full independent WB and NB transmit and receive capability that also allows LAMPS operations while concurrently operating a NB digital network.

LAMPS WB-LB Rx and NB-UB Tx bands. As may be seen the NB networking could still proceed even though LAMPS is up, however the links would have to be reversed from what is shown, since interference would exist in the NB-UB Rx path due to the LAMPS SRQ-4 NB-UB Tx operation.

4.0 PREDICTED COMMUNICATION PERFORMANCE

Using a computer (PC) program called SLAM, that was developed at NCCOSC RDT&E Division, a parametric examination of the communication performance of any new system, including the effects of multipath, propagation, diffraction, and ducting can be performed. The plots that follow were developed for a few of the foregoing key configurations. The actual characteristics of the present LAMPS III system were used in the analysis including the system losses that affected both the transmitted signal as well as the received signal. These losses were provided in the LAMPS engineering documentation in Navy files. The factors that were included in the link analysis are listed in figure 3.10. The term called out as REQ stands for required signal margin above that which will just allow achieving the desired BER at the specified data rate.

Relative to LAMPS III we are dealing with specific known system parameters. RF power (Pt), transmit, and receive antenna gains (Gt,Gr), and system losses (Ls) are all known. Therefore, the variable is the channel transmission losses (Lc). In the figures shown, link margin will be plotted in decibels on the ordinate versus the propagation range between the two antennas in nautical miles (nmi). The results are plotted for the nominal frequency bands. The calculations assume a solid state (ss) power amplifier with an RF power output of 40 watts. Because of the superior reliability of these solid state devices, at this power level, and the need for extremely high reliability in the special communication package just described, the solid state 40-watt PA was used for the analysis. Using the SLAM PC-based model, explorations were made of the effects of parametric variations from the present LAMPS III system architecture as a reference. This incidentally, was how the merit of the new special communication package was assessed including the need for a 6-dB omni antenna and a low loss system. For the computations we assumed that the antenna on each ship was at 100 feet above sea level (DD 963), and this results in a maximum LOS range of about 20 nmi. When sufficient excess power or margin is available, range values will be shown on these plots in excess of the LOS limit and out to a diffraction loss limit. The criteria of goodness of a link condition is the level of the system link margin at 20 nmi and the level of the multipath worst case signal attenuation. This will become clearer after the plotted data are examined.

Figure 3.11 shows the expected performance of the LAMPS communication link between the high-gain LAMPS antenna and the LAMPS "0" dB antenna as a function of separation range, assuming a communication WB data rate of about 5 Mbps with a E/No = 12 dB. We see that at the 20-nmi range the excess signal strength is about 7 dB when using a 40-watt solid state PA, at either the high-gain or omni antenna side of the link. The sharp downward spikes are due to multipath signal degradation effects. The worst of these multipath signal degradations can be seen about +4 dB away from

$$P_T + G_T + G_R - L_S \geq L_C + N_D + B + Req$$

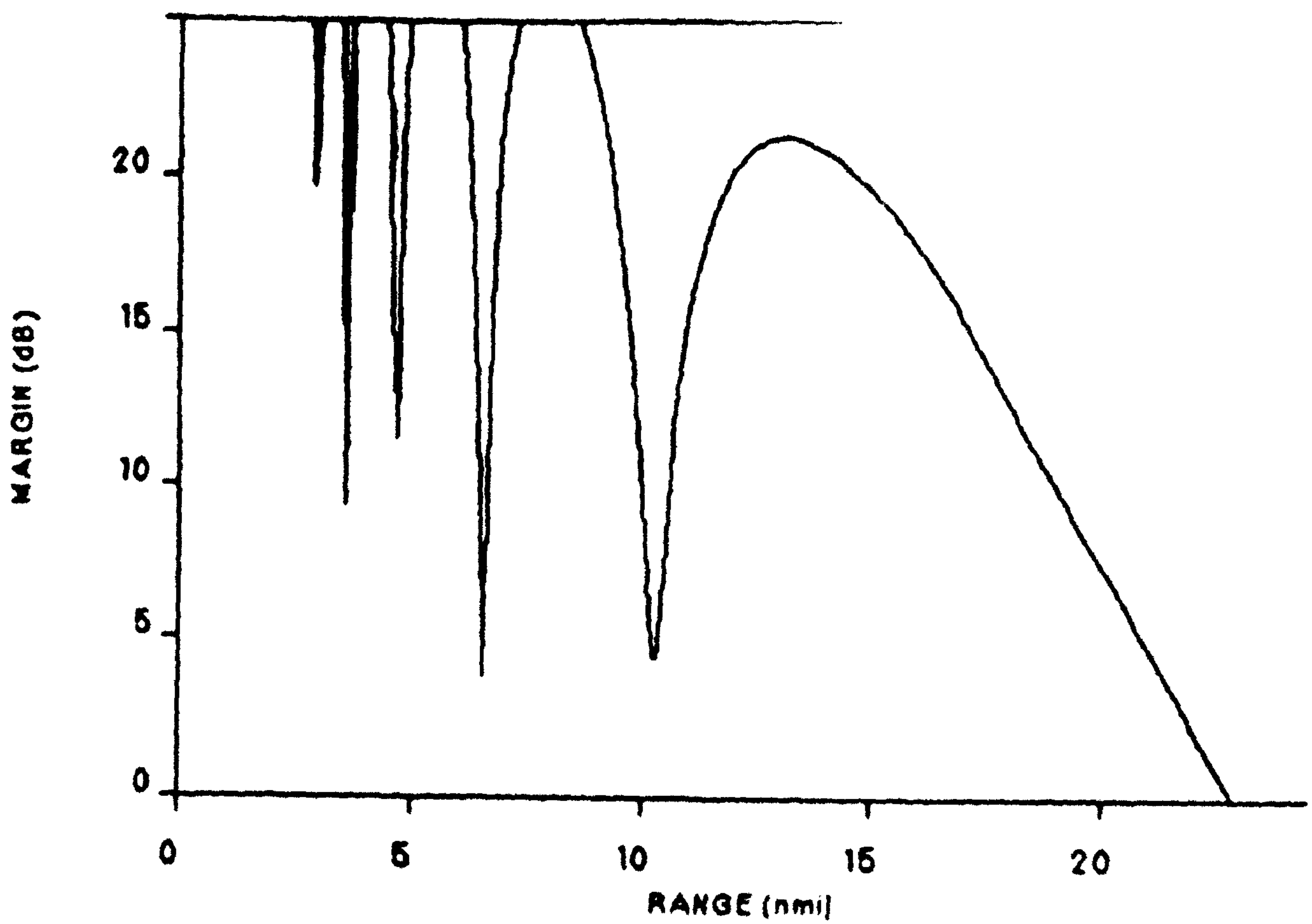
RF Power Requirement

- P_T – Tx power
- G_T – Tx antenna gain
- G_R – Rx antenna gain
- L_S – System loss
- N_D – Noise density
- B – Bandwidth
- Req – Required SNR (12 dB for 10^{-6} BER, QPSK)

L_C – Channel transmission loss (20 nmi)

- Free space
- Rain
- Reflection
- Diffraction

Figure 3.10. Link equation, dB.



Wideband (WB) Communications
0 dB omni to high-gain antenna
Pt = 40 watts s.s.; M = +7.3 dB at 20 nmi

Figure 3.11. Phase I system.

being of concern. This may be regarded as the lowest safety margin that exists in this link. The received signal power is strong enough to allow communication out to ranges of about 23 nmi and then be overcome by diffraction loses. This calculation used the actual documented transmitter and receive system loses.

Figure 3.12 shows the expected communication performance for a NB communications case. The data rate is taken to be about 150 kbps on a link between a "0" dB omni antenna and a +6-dB omni antenna on the special communication package. This would correspond to the performance one would get using the special communication package on one ship and the LAMPS omni on the second ship. The signal margin at 20 nmi can be seen to be over 6 dB when a 40-watt PA is used and a E/No = 12 dB is required.

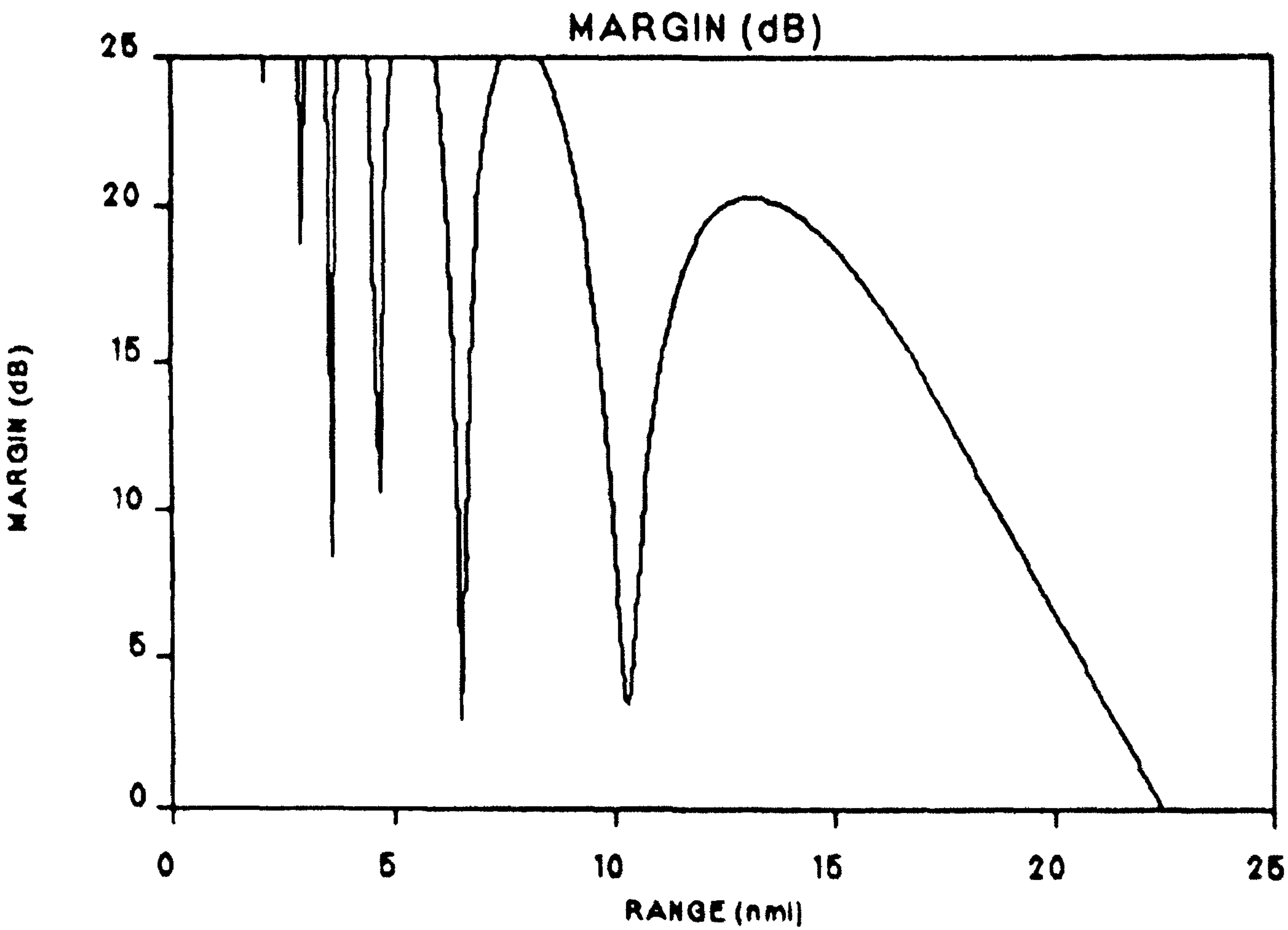
5.0 LAMPS III DEMONSTRATIONS OF A SHIP-TO-SHIP HDR COMMUNICATION SYSTEM

LAMPS demonstrations, that will be employed in the evolution of this new ship-to-ship high data-rate communication capability, have many facets. The first of these demonstrations begins with tests in the laboratory. At the next level we will make a bridge between the laboratory and the world of the Navy combatant ships that already have a LAMPS system onboard. The results of these efforts will provide a final answer regarding the technical direction that could maximize the benefits and operational capability possible in any fielded system. This last phase would be the focus of any planned Advanced Technology Demonstration (ATD). Consequently, the work that will go on in the early two phases will be performed with this ultimate ATD objective in mind. The specifics of the areas of investigation, in each of the above categories, is contained below.

5.1 LABORATORY TESTING/DEMONSTRATIONS

The work in this area has already begun this year because of the support provided by NESEA. Although the documentation supporting the LAMPS system is quite extensive, there are still many areas where detailed engineering information deficiencies exist. Some of these information deficiencies occurred because the suppliers of LAMPS subsystems apparently believed their interests would not be protected if they revealed detailed design information and data on subsystem characteristics. In these situations, NESEA conducted various laboratory measurements on the LAMPS equipment to reveal this needed information.

Later sections will discuss implementation techniques that have been considered to circumvent certain component issues that may not be easy to solve at this time. These issues if not resolved could prevent conducting basic ship-to-ship link performance tests. The testing and evaluation of these approaches will be first performed at the NESEA laboratory. If satisfactory results are achieved then installation in NESEA's LAMPS test systems, called MOD 3.5 units, will be performed to allow laboratory system testing. The MOD 3.5 LAMPS units are not full operational system replacements; therefore, this use of these assets is acceptable



Narrowband (NB) Communications
0 dB omni to 6-dB omni
Pt = 40 watts; M = +6.6 dB at 20 nmi

Figure 3.12. Phase II system.

5.2 SHIP-SHORE AND SHIP-TO-SHIP HDR COMMUNICATION DEMONSTRATIONS

The laboratory communication system level testing, described in 5.1, will attempt to simulate some of the test conditions that would occur in an at-sea test. Upon the successful conclusion of these laboratory tests, using modified SRQ-4 and modified ARQ-44 (Mod 3.5) units, these would then be integrated at NESEA to simulate ship installation. The LAMPS antennas could be mounted on a high outdoors platform, that presently exists at NESEA's or facilities at Patuxent MD. NESEA would coordinate with appropriate NAVSEA and operational force elements to obtain the services of a LAMPS III ship. This ship would support a ship-to-shore HDR communication test. The test objectives will be limited to simply demonstrating that a high quality WB channel can operate over a 20-nmi path at an acceptable BER. After this test has been thoroughly and satisfactorily conducted, then the next step will be to modify a second ship by installing a modified NESEA R/T drawer in the shipboard SRQ-4 rack and also integrating a modified NESEA ARQ-44 terminal unit. Ship-to-ship tests will then be conducted at sea at various ranges and shipboard EMI conditions. This demonstration will also reveal the level of interference that will be experienced by the LAMPS receive system in the WB mode. Also, the level of RF interference that can occur under various EM conditions when the LAMPS transmitter is emitting a WB signal, using either the omni or high-gain directional antenna, will be examined. During the course of this demonstration, test plans need to be implemented that will permit Low Probability of Intercept (LPI) to be evaluated. In this evaluation, the high-gain antenna on each ship will be directed at each other permitting the lowest radiated power level. This will result in the lowest attainable probability of detection and bearing determination LPI.

5.3 OPERATIONAL LAMPS HDR COMMUNICATION SYSTEM ADVANCED TECHNOLOGY DEMONSTRATION (ATD)

Much of the work in this section will in all likelihood continue under an Advanced Technology Demonstration. This demonstration will be performed using a ship-to-ship LAMPS HDR communication system with a maximum operational capability. This capability will include a maximum number of channels in an omni to 6-dB omni (special commmunication package) NB network, a WB high-gain antenna to "0" dB omni antenna mode, and an LPI test using the WB mode for a high-gain antenna to high-gain antenna test. The findings from the efforts conducted in sections 5.1 and 5.2 will provide vital information needed to address the foregoing operational configurations. The ship-to-ship demonstrations stated earlier will be focused on demonstrating the basic WB link connectivity in its simplest form. This philosophy has been applied to constrain the range of technical issues that require resolution before the basic testing can proceed under the FY 93 funding. Nevertheless, the technical, equipment, and component issues that act to restrict the LAMPS III HDR communication system from achieving its fullest potential will be identified. This will allow appropriate corrective actions to be addressed together with schedule and funding requirements. The implementation of any significant changes will take place, more than likely, under the ATD program.

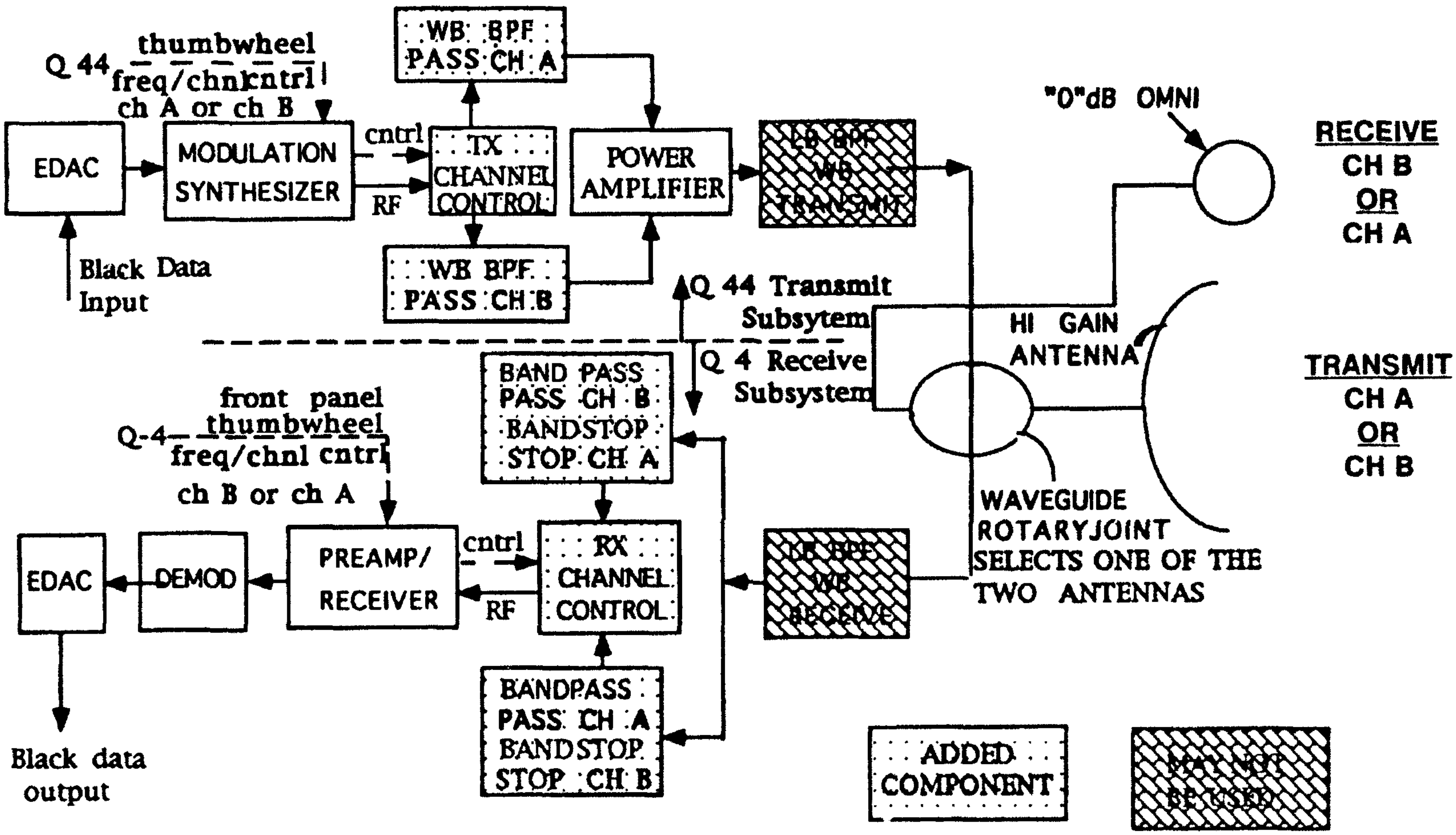
5.4 LOW COST DEMONSTRATION SYSTEM

A modified LAMPS R/T subsystem that will allow WB ship-to-ship link testing in one of two LB channels with a low development cost is shown in figure 5.1. To avoid the costs and technical issues associated with the frequency shifting of the WB Tx/Rx to the upper band, this system design is restricted to only the lower LAMPS band of operation LB. One of two new bandpass WB filters would be selected for the LB transmit chain of the ARQ-44 prior to the PA and one of two bandpass/bandstop filters would be selected for the SRQ-4 LB WB receive path. The bandstop filters are designed to maximize the attenuation of transmitter energy into the receive path. Each filter would ideally have a 3-dB bandwidth about equal to about 10 MHz. When the WB transmit system is using filter band A, it is essential to avoid receive system damage, so that the receive system can only use filter band B. The channel control subsystem is to provide this protection. This requirement therefore means that the other ship must transmit on filter band B and receive on filter band A. The frequency separation between A and B and the band stop filter attenuation are major parameters in determining the degree to which the receive system is isolated from the transmitter. If the isolation level is in the range of 90 dB then it is expected that this should provide a comfortable margin. The technical challenge, aside from the isolation level, is the installation of the two transmit RF bandpass filters (A and B) in the ARQ-44 (top of figure 5.1), and the installation of two passband/bandstop RF filters(A&B) for receive in the R/T drawer of the SRQ-4 (bottom of figure 5.1). The installation must be made in such a way that the system can be restored to its original LAMPS III configuration when testing is completed.

The installation of the RF filters in either the SRQ-4 or the ARQ-44 may require that the present WB/NB diplexer filter be temporarily removed to make room. Since NB operation is not being used in this test, this diplexer filter is not needed. In the WB transmit path, the removal of the LB WB diplexer filter could result in 3 dB more transmitted RF power.

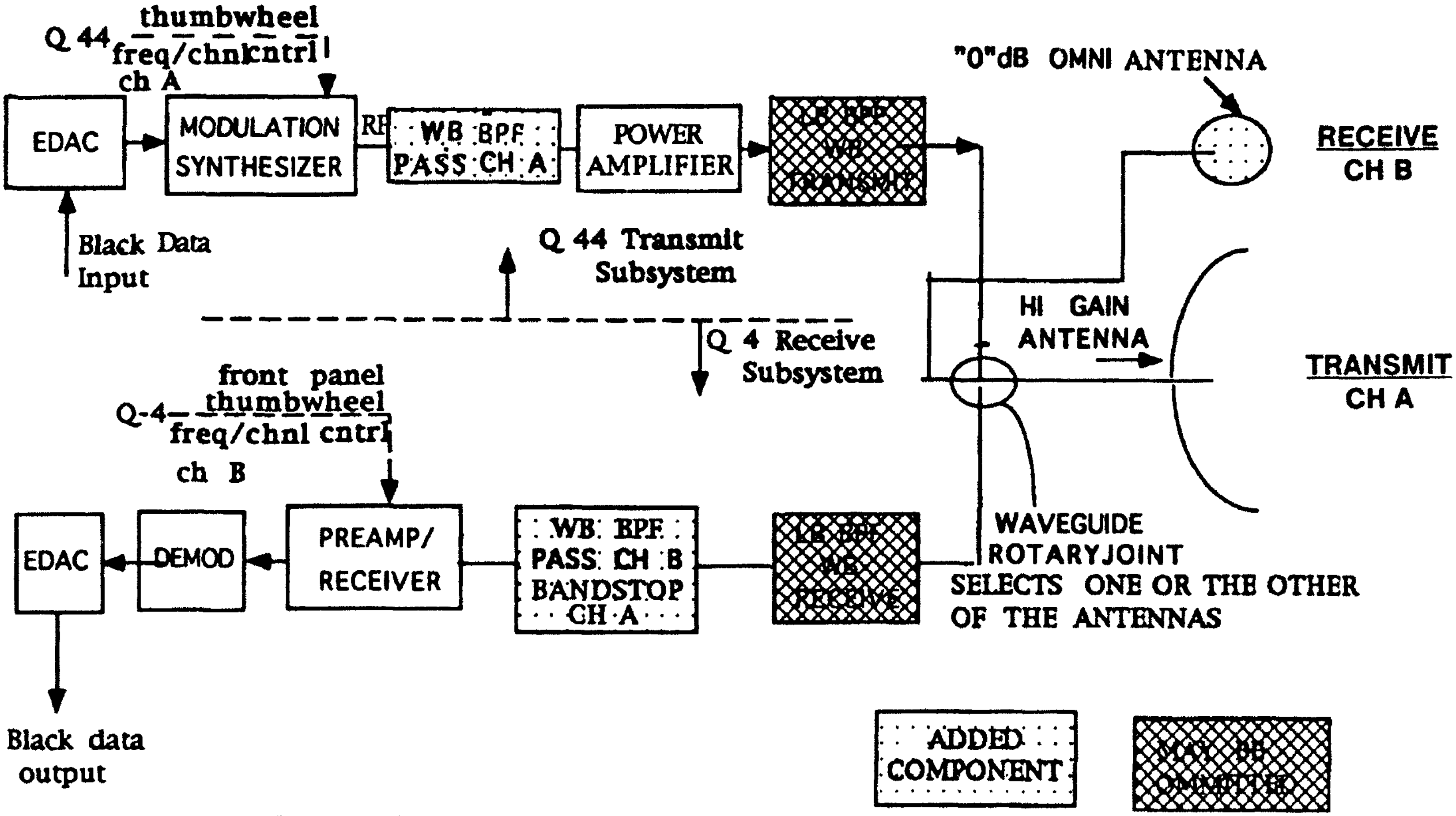
5.5 MINIMAL COST DEMONSTRATION SYSTEM

The foregoing system concept allows two-channel flexibility in the selection of transmit and receive frequencies between the ships. This may be desirable if, for example, one of the ships is having EM interference with its signal reception or if for various reasons it does not wish to transmit in a particular part of the band. If we eliminate this flexibility and assign one ship to transmit in band A and the other to transmit in band B, a 50-percent reduction in the number of RF filters occurs, together with an easier less space-demanding installation. The provisions for Tx/Rx channel control shown in figure 5.1 also is eliminated since the transmit system on a ship cannot switchover to operate in this band for reception. This is why the system in figure 5.2 is regarded to be the lowest cost system. Aside from cost, it may be possible to install this configuration without removing the present NB/WB diplexers from the ARQ-44 and SRQ-4 R/T subsystems. This matter will require more engineering evaluation before a



LOW COST DEMONSTRATION OF LAMPS WB SHIP TO SHIP COMMUNICATIONS

Figure 5.1. Full duplex HDR communications using LAMPS assets.



LOWEST COST DEMONSTRATION OF LAMPS WB SHIP TO SHIP COMMUNICATIONS

Figure 5.2. Full duplex HDR communications using LAMPS assets.

decision is made. Filters A and B are both located in the LB at the extreme ends of the diplexer broadband filter (if still installed) and have a 3-dB bandwidth of about 10 MHz. It is also the goal of this design to avoid changes in the present LAMPS frequency synthesizer subsystems to minimize WB link demonstration costs.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

A simple minimal cost demonstration of the WB communications capability of a modified LAMPS III system is being planned to provide HDR ship-to-ship full duplex communications at about a 5 megabit/second dat` rate. From this preliminary investigation, this appears to be achievable out to a LO' ship-to-ship range of 20 nmi. A demonstration of this new WB capability appears to require a minimum investment since the most costly elements of the system are already contained in the existing LAMPS system. A detailed engineering assessment of not only the concepts presented but other approaches is underway.

The experience to be gained in the FY 93 at-sea WB communication demonstration will be valuable in terms of further defining WB and NB operational concepts and implementation approaches. The additional effort that will go on in FY 93 will address the best approaches to take to achieve a maximum receive and transmit reference frequency shifting. This frequency shifting is required so that the maximum isolation can be achieved in both WB point-to-point communication as well as NB networking. LAMPS III testing of the modulator synthesizer during the FY 92 has revealed a need for a major increase in transmitted carrier frequency agility so that regions well outside present transmit band can be operated in.

The channelization that exists in the LAMPS III ties both the channel in the WB shipboard receive to the NB shipboard transmit channel (i.e., when on channel 5 on WB receive, the systems' frequency synthesizers and frequency offset/thumbwheel divider functions causes the channel on NB transmit to also be 5). These specific existing LAMPS frequency synthesizer design characteristics are not applicable to the case where full duplex WB or NB operation is used vice the WB/NB receive/transmit that is used in the shipboard LAMPS III. The large difference in bandwidth between the NB and WB channels does not exist in the new system since the channel bandwidths are the same for receive and transmit.

The special communications package is a very attractive concept for several reasons. From the results of the communication link calculations, presented earlier in this report, it appears to be the only practical way of achieving omni-to-omni networking because of the very desirable 11- to 14-dB link improvement that is achieved when line loss is greatly reduced and a 6-dB gain over the LAMPS omni antenna is used. The transmit and receive path loss reduction that is achieved occurs because the 6-dB omni antenna is directly connected to the receive and transmit diplexer output port.

This compares to the waveguide loss in the LAMPS III which starts below deck and runs as much as 100 feet up the mast through various couplers and joints to the antennas. Because of this and the "0" dB gain omni antenna, LAMPS III has no possibility of achieving NB networking at a 20-nmi range using a NB data rate of 150 bps. The use of the special communication package at the other end of the LAMPS III omni link boosts the receive signal by about 11 to 14 dB compared to LAMPS III omni reception. A design of the communication package needs to consider the use of a 40-watt solid state power amplifier because of its low cost, very high reliability and the relative simplicity of its power supply. As stated earlier, this concept in its simplest form, when used on a non-LAMPS ship, such as a carrier, or shore site, allows for WB transmission to the LAMPS III ship and NB reception from it.

6.2 RECOMMENDATIONS

The U. S. Navy has a valuable resource in the LAMPS III system and this has been demonstrated in its remarkable operational performance. LAMPS MK III has been operational in the Fleet for at least 10 years. It is a well engineered system that in many ways is still very sophisticated. Its excellent performance results from the soundness of its engineering. It is an example of what is possible in operational Fleet electronics. For these reasons it represents a very sound foundation upon which to create another remarkable level of LAMPS III usefulness to the Navy. LAMPS MK III presently has an operational role which it performs efficiently and effectively. Therefore, variations from its present design have to be evaluated carefully to be sure that no reduction in present operational capability will occur if any design changes are to be implemented. The case of the special communication package is attractive because of a 11- to 14-dB signal strength improvement over a LAMPS SRQ-4 omni receive system. It also eliminates the direct RF interfacing requirement between the shipboard system (SRQ-4) and the onboard LAMPS helicopter terminal (ARQ-44). One disadvantage, however, is that the interfacing issues may now have moved up the mast and now be an Electromagnetic Compatibility (EMC) issue.

On the other end of operational concerns is the question of achieving an LPI of the ship radiating SHF signals. The high-gain LAMPS III, antenna operating into another ships LAMPS high-gain antenna, can transmit at power levels reduced by the value of the receive antenna's gain, relative to a "0" dB omni antenna. Thus, for example, if one assumes that the receive high-gain antenna was 30 dB above the omni and the transmitter power for the high-gain antenna was 10 watts when transmitting WB to an omni antenna; then the high-gain antenna is used to replace the receive "0" dB omni, the transmitter's power can be reduced by 1/1000 and it would only be 0.010 watts. This low power in the main antenna beam, plus the narrow antenna beam pattern, makes for low detectability or LPI. We have seen earlier how the high-gain LAMPS III antenna, used for transmitting WB from a ship can be successfully received on another ship when that ship is using a "0" dB omni at 20-nmi range. If LPI is desired in the WB mode then the second ship would also use the high-gain antenna to permit the lowest level of transmitted energy. What this scenario leads to is that LPI is not readily achieved with a special communication package. To achieve an LPI capability, at the

WB data rate, it will therefore be necessary to interface the helicopter ARQ-44 WB transmit capability directly with the shipboard SRQ-4 WB receive system in the below deck LAMPS III facilities, thus accepting the line losses in order to use the high-gain antenna.

As can be seen, there are a variety of possible operational configurations, each with very desirable features. What is recommended is that the technical investigations and testing continue so that needed technical insight might be developed. This will be done within the LAMPS III framework to deal with the identified technical questions related to attaining a LAMPS WB/NB ship-to-ship communication capability.

7.0 BIBLIOGRAPHY

1. Federal Systems Division of IBM Corporation/Naval Air Systems Command. October 1987. LAMPS MK III Weapon System Information Manual, UNCLASSIFIED A-1H60BB-WSI-000, Technical Manual, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA 19111.

2. Federal Systems Division of IBM/Naval Electronic Systems Command, 1 September 1984, Radio Terminal Set AN/SRQ-4 UNCLASSIFIED EE185-AA-OMI-010, Technical Manual.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1993	Final

4. TITLE AND SUBTITLE System Investigation Into the Applicability of LAMPS MK III ASSETS TO IMPLEMENT A HIGH DATA RATE SHIP-TO-SHIP COMMUNICATION SYSTEM

5. FUNDING NUMBERS
PR: CHB5
PE: 0602232N
WU: DN300067

6. AUTHOR(S)
James P. Rahilly

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152-5001

8. PERFORMING ORGANIZATION REPORT NUMBER
TR 1562
Volume 1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Technology
Office of Chief of Naval Research
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division has over the previous year been exploring the technology and system approaches that could provide, on a minimum development cost basis, a High Data Rate (HDR) communication link connectivity between surface ship elements of a U. S. Navy battle force. HDR is defined as being data rates equal to or greater than the Bell T1 rate of 1.54 Mbps.

14. SUBJECT TERMS
super high frequency radio
communications
SHF

15. NUMBER OF PAGES
43

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE (Include Area Code)	21c. OFFICE SYMBOL
James P. Rahilly	(619) 553-3426	Code 824

NSN 7540-01-280-5500

Standard form 298 (BACK)

INITIAL DISTRIBUTION

Code 0012	Patent Counsel	(1)
Code 0142	K. J. Campbell	(1)
Code 80	K. D. Regan	(1)
Code 804	R. D. Peterson	(1)
Code 804	J. W. Rockway	(1)
Code 804	G. A. Clapp	(1)
Code 82	R. J. Kochanski	(1)
Code 824	J. B. Rhode	(1)
Code 824	H. W. Guyader	(1)
Code 824	J. H. Schukantz	(1)
Code 824	P. Li	(1)
Code 824	J. Ho	(1)
Code 824	J. Rahilly	(13)
Code 83	R. L. Williams	(1)
Code 833	J. S. Buehler	(1)
Code 842	W. Christian	(1)
Code 843	D. M. Gookin	(1)
Code 961	Archive/Stock	(6)
Code 964B	Library	(2)

Defense Technical Information Center
Alexandria, VA 22304-6145 (4)

NCCOSC Washington Liaison Office
Washington, DC 20363-5100

GIDEP Operations Center
Corona, CA 91718-8000

Space and Naval Warfare
Systems Command
Washington, DC 20363-5100 (2)

Department of the Navy
PEO/ASW
Washington, DC 20363-5100 (3)

Naval Postgraduate School
Monterey, CA 93940-5000 (3)

GTE Government Systems
San Diego, CA 92108-3113

Stanford Telecommunications
Santa Clara, CA 95056

Center for Naval Analyses
Alexandria, VA 22302-0268

Navy Acquisition, Research & Development
Information Center (NARDIC)
Washington, DC 20360-5000

Naval Command, Control & Ocean
Surveillance Division Detachment
Warminster, PA 18974-5000 (2)

Naval Electronic Systems Engineering
Center, St. Inigoes
St. Inigoes, MD 20684-0010 (4)

California Microwave, Inc.
Sunnyvale, CA 94086 (3)

Paramax Corporation
Salt Lake City, UT 84116 (3)